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The Mechanical Equipment
of the
New South Station
Boston, Mass.

By Walter C. Kerr, Member A. S. M. E.

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NEW SOUTH STATION

BOSTON, MASS.

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WALTER C. KERR, M. AM. SOC. M. E.

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No. 845.*

THE MECHANICAL EQUIPMENT OF THE NEW SOUTH STATION, BOSTON, MASS.

BY WALTER C. KERR, NEW YORK, N. Y.

(Member of the Society.)

Assisted by HENRY J. CONANT, WILLIAM W. CHURCHILL, FRANCIS BLOSSOM, J. P. COLEMAN, AND CALVERT TOWNLEY.

THE terminal station of a railway system comprises essentially the approaches, yards, and side tracks, the train shed with its stub tracks, the head house—usually in the form of an open quadrangle around three sides of the train shed—and the engineering appliances which are required to serve the property and its tenants. It is primarily of these engineering appliances in connection with the Boston South Station that this article treats. It has been thought proper to have the various sections described by those who principally designed them, or who have been intimately connected with the work and who should therefore be regarded more as having created this mechanical engineering plant than as merely assisting the contributor in the preparation of this paper.

The requirements being somewhat miscellaneous and not so easily identified as those of the large structures such as train shed and head house, were left somewhat longer undetermined than the former. The trustees realizing, from long personal experience, the difficulties surrounding the division of such work among many contractors, sought for a concern who should be both engineers and contractors and who had facilities for expeditiously designing and executing all of the work required, notwithstanding it was of such a nature as would ordinarily be much subdivided.

In the search for an organization capable of undertaking the entire work, a choice was made of the Westinghouse interests, and

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Fig. 152.—South Station, The Boston Terminal Co.

brief negotiations with Westinghouse, Church, Kerr & Co. led to an agreement by which the latter was given access to such information as was on hand and full opportunity to acquire or create the requisite data, upon same to completely design and specify all of the engineering work required to properly serve such a terminal, and to submit bids for the construction of the work prior to the admission of others to like privileges. This agreement was faithfully and literally kept by the trustees and their representatives notwithstanding the urgent pressure brought from many sources demanding data on which to figure upon all or part of the work.

The design of this plant involved more than ordinary engineering complication because of the peculiar situation of the terminal within 90 feet of tide water, in a very open soil full of old docks and timber cribs, with some portions more than 8 feet below extreme high water; also the peculiar shape and exposure of buildings, together with the climate of Boston and the occupancy of the premises by various roads.

The work was at once taken in hand and an engineering corps formed within the Westinghouse interests to handle it. It would be quite improbable that any one engineering office would have at its command all of the talent of the various kinds required for performing engineering work over so broad a range, and only in an association of diversified interests, in which manufacturing and engineering extend over a wide field, could a corps of engineers be instantly organized, the work put in hand without delay, without experiment as to the fitness of men and without question as to the harmony of their coöperation. Very few engineers appreciate of just what such work chiefly consists. It being generally presumed that this was largely an electric installation, there was a natural inclination to treat it as an electric problem. Those more intimately connected with such work would, however, realize that the electrical part is, on the whole, small relatively to other divisions and in point of expenditure is a comparatively minor portion of the plant. In fact, no one section predominates conspicuously unless, possibly, the interlocking switch and signalling system.

It was realized that the first requisite in undertaking the design of this work was quick determination of what it should comprise, for the time being short, it could not be done many times over in the light of growing knowledge obtained from continued redesigning. The first step, therefore, after carefully contemplating the

FIG. 154.—VIEW OF YARD TAKEN FROM BENEATH TRAIN SHED, AFTER BLIZZARD OF FEBRUARY, 1899. STATION HAD BUT JUST BEEN PUT IN OPERATION.

probable requirements, was to despatch men to all of the principal terminals of the country to collect data as to the requirements of such terminals, the ways in which they had been best filled, and especially of the features, which had been incorporated, that were in use found inadequate or disadvantageous. A couple of weeks of such investigation brought these various engineers together in Boston with their associates, who had meanwhile been mapping out general plans of operation and getting ready foundation drawings of the property, train shed, power-house site, head house, and determining levels and various quantities. The corps in all comprised some fifteen men, in addition to which S. Homer Woodbridge, heating and ventilating engineer of Boston, was retained as consulting engineer to assist in the design of the heating and ventilating plant. The work then definitely started, and within 90 days from the time that it was first contemplated, the designs were finished.

In addition to the detailed specifications, there were prepared a series of monographs on each important section of the work, giving the reasons for the methods adopted and involving considerable of the data on which the work was based. These discussions contained much regarding methods or apparatus considered but discarded, as well as those adopted, and the monographs were used largely in lieu of the specifications in the consideration of the matter by the board. Complete estimates were also made and the plans and specifications were accompanied by a proposal to construct the entire plant.

The plans and specifications were subjected to the most searching scrutiny and criticism. The writer was chosen to present the matter in the interest of the various Westinghouse concerns represented in the design, and after it had been fully laid before the board and had met their general approval, a board of engineers was convened, comprising the chief engineers of the four tenant railroads and certain others connected with said roads in managerial capacities, together with the resident engineer of the Boston Terminal and Dr. E. D. Leavitt, of Cambridgeport, Mass. The designs were laid before this board, the specifications read, monographs considered and alternate methods discussed. After many sittings, the plans and specifications were approved in substantially their original form, except as to such modifications as had meanwhile become necessary, due to other changes in the station design.

The plans and specifications then going back to the board with the engineers' unanimous approval, the negotiations turned to the financial side, under the inconvenience which often attends the presence of only a single bid and requiring justification of the price. This necessitated investigation of the cost of engineering work of other terminals, and a satisfactory demonstration that the plant could be built for, and was worth, the price asked. It was shown that by the method in which this work was taken up, designed and to be executed as one complete undertaking, The Boston Terminal Company was securing an advantage of about $100,000 over the fair *pro rata* price which it should have cost when judged by the contract prices paid to various contractors in other terminals, a substantial portion of this gain being represented by the economies possible where work is thus designed and executed by one organization experienced in all the work undertaken.

Due consideration was given to the relative merits of the several ways in which so diversified a plant might be installed. The conditions were such that the advantages of having the work done, and the operative results assured, by one contractor were considerable. The trustees, however, could not justify an award without competition except on terms proposed by them, the nature of which fully protected the interests of The Boston Terminal Company, assured to it the greatest value for the expenditure involved, and warranted their unanimous action in placing the contract for the entire work of construction in the hands of the engineers who designed it.

As this engineering work approached completion, an operating force was organized chiefly from men who had worked on the erection in various departments, the entire plant subsequently put in commercial operation, logs prepared and daily records kept, and all necessary details perfected. The plant, therefore, was not merely made ready for use, but was put in operation with a completely organized force so that it could be assumed by The Boston Terminal Company with the least risk.

Many instances might be cited to indicate the quality of the design and construction of the engineering work of this terminal, but none could be more significant than the record of operation on first starting. It will be generally admitted, when a large and more or less complicated plant, involving many functions, is first put into operation with the various parts interdependent

upon each other, that the first few weeks form a critical time during which many shortcomings may be properly forgiven. In this instance, however, the whole plant was put in operation in the dead of winter, and Boston was immediately snowbound; the temperature dropped below zero, putting every section, from the switch and signalling apparatus to the leader-thawing devices, into emergency service. The result can be stated almost without words. Nothing happened. The plant operated day after day without apparent relation to the hard service imposed. Nothing failed, not even so much as a joint in all of the many miles of piping connected with the hot-water heating apparatus, notwithstanding the fact that a large portion of this pipe was temporarily supported in mid-air in permanent position through the site of the express buildings, which were not then erected. (See Fig. 193.)

All of the conditions surrounding this engineering work, from its first inception to the placing of the last portion in position, were all conducive to the obtaining of the best results at the lowest cost. The patience of the board of trustees, in understanding the detail of the work, was unusual; the earnest coöperation of the resident engineer and the hearty good-will which surrounded this entire work, contributed not a little to the results secured.

It will be noted that this engineering work was conducted on a basis which is growing more prevalent, of entrusting the work of engineering design and contract for construction to the same engineers. This custom seems to have obtained more in mechanical than in any other form of engineering, due, perhaps, to the fact that mechanical engineers and mechanical engineering contractors are more nearly the same type of men than civil engineers and most civil engineering contractors; or architects and most builders. Another reason may be that mechanical engineering developed into large proportions long subsequent to other forms of engineering, also subsequent to the opportunities for educational advantages and is closely linked with manufacturing processes. It has thus, for reasons not altogether easy to analyze, become the custom for mechanical engineers to associate themselves with manufacturing or contracting corporations.

The growing tendency of purchasers to concentrate the responsibility of design and construction, has further led to the placing of large engineering work in the hands of contractors who first design and then construct to their own designs and specifications. Whatever be the technical objections to this method of conduct-

ing work, or whatever arguments may be urged against its theoretical feasibility, there seems to be no doubt as to the good results of its practice and the conduction of much work in this line has led the writer to believe that it is one of the best methods yet adopted. There seems to be no incompatibility of relationships and the universal satisfaction which it has yielded warrants a fair word in its favor. It should, however, be understood that the fact that an engineering concern is so situated as to be able to do such work, in no wise incapacitates it for conducting contracting along the usual lines of bidding to the plans and specifications of others. It may not be too broad a statement that many classes of engineering design gain little from so-called disinterestedness, but gain much from a certain balance and gravity which follow only from the close touch of personal experience, and from the realization that the designer must responsibly execute his design within fixed commercial limitations. In other words, a strong guarantee of accuracy and quality results from concentrated interested responsibility. To moralize slightly further, the virtues of competition are not always realizable in certain classes of work, and such work as is here described is peculiarly the type which, for the production of the best results, requires a closer intimacy than would ever be gained through the natural channels of competition, and contributes to results of an order not usually possible. This may not be engineering, but it is very near it.

In the division of work, the contributor of this article undertook the general management and presentation, giving more or less attention to all sections. The entire undertaking was put in responsible charge of Mr. Henry J. Conant, then manager of the Boston office of Westinghouse, Church, Kerr & Co., who prepared specifications and who afterwards had charge of the detail designing and execution of the work, etc., while the general design and coördinating of the various designs for different sections was in the hands of Mr. W. W. Churchill, mechanical engineer of Westinghouse, Church, Kerr & Co., who was assisted in this by Mr. Conant, and who also assisted in preparing specifications and in the execution of the work. The switch and signal work was designed entirely by the Union Switch & Signal Co., of Pittsburg, one of the affiliated Westinghouse interests; this work being conducted by Mr. E. H. Goodman. The electrical work was designed through the association of the Westinghouse Electrical &

Manufacturing Co., and more immediately by its Mr. Fowler. The ice and refrigerating plant was designed by Mr. Francis Blossom, in charge of the ice and refrigerating department of Westinghouse, Church, Kerr & Co., while the Westinghouse Air Brake Co. contributed to the air-brake testing outfit.

The Problem.

Most of the historical facts here presented were obtained through the courtesy of Mr. George B. Francis, the resident engineer of The Boston Terminal Company, to whom it is desired to extend thanks for the assistance which he has thus rendered.

Some time early in January, 1896, the project for a union station for the use of all the railroads entering the city of Boston from the south, was first seriously considered. During the first six months of that year a suitable site was selected and a large part of the land acquired.

The engineering force, with Mr. George B. Francis at its head, reported for duty on July 1st, and active surveys immediately commenced. While this work was in progress, the manager of the terminal, Mr. John C. Sanborn, and the chief engineers of the interested roads, visited various European railroad terminals; the architects and engineers were preparing plans and a fund of information bearing on the project was accumulated. Among other data thus collected was that shown in the accompanying map (Fig. 155). This diagram shows the need for large terminal facilities in Boston, and the exhibit made justifies the existence of the new South Station, the largest railroad station in the world.

In anticipation of revolutionary changes in the methods of handling suburban traffic, it was decided to so build the new station that new motive power could be advantageously employed, and so that a large increase in suburban trains, due to smaller train units and more frequent service, could be easily handled.

In the first plans made, all tracks were arranged on a single floor; but after providing as well as possible for all train service and for desirable features for handling baggage, and after developing several methods of handling electric cars, it was ascertained that no more than 28 tracks could be secured, while the aggregate of tracks in the stations which the South Station replaces, was 25.

There being no reasonable hope that a greater width of land could be secured, consideration was given to the possibilities of

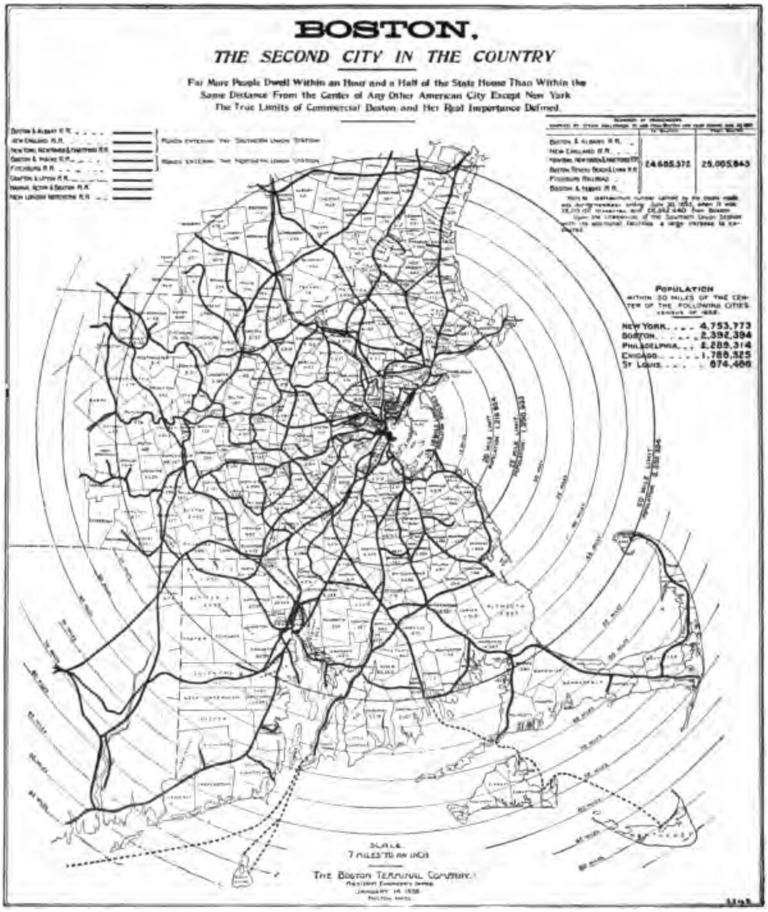

FIG. 155.—MAP OF THE TERRITORY WITHIN FIFTY MILES OF BOSTON.

Showing railroad routes northerly and southerly of an east and west line; the former routes leading to the north terminal station, and the latter to the south terminal station.

About 50,000,000 passengers are carried to and from Boston by these routes each year, nearly equally divided between the two stations.

The close approximate population within the 50-mile or, say, suburban limit is 2,392,000. Within the same limit around Philadelphia it is 2,2[illegible]9,000; around Chicago, 1,788,000; around St. Louis, 874,000; and around New York, 4,754,000; New York only exceeding Boston.

separating the suburban short distance service from the through or long distance service, placing them at different levels, thereby greatly increasing the room for the tracks in a given area.

The first study of the problem diverted the proposed suburban tracks from the main approach tracks about half a mile from the station, and by a gradual rise brought several tracks on either side of the train shed to a level about 24 feet above the main floor. These were to be stub-tracks like those on the floor below. This arrangement did not do away with the necessary switch system for making up trains outside the station for each floor level, and upon its development it was seen that if the elevated stub-tracks could be connected in the form of loops, the train movements would be very much lessened and the number of switches at the entrance largely reduced. The great width of the station made this possible and it was accordingly done.

This was, therefore, the first loop study. There was much doubt regarding the advisability of having upper platforms about 28 feet above the main floor, as would be the case if high platforms were used, on account of appearance, stair climbing, handling of baggage, and the smoke and steam from the locomotives below. The approaching grades were also steeper than was desirable.

The possibility of a suburban loop track service upon a floor beneath the main train shed was next considered. The main floor was raised to the highest level practicable without the use of stairs and the level of the loop tracks determined at a grade 17 feet lower and some 8 feet below very high tides. This immediately introduced the study of waterproofing the great loop area to shut out the tide water, and due consideration indicated that this could be done without prohibitive cost.

Placing the loop tracks 17 feet below the main floor level and using high platforms for the loop service, made easier approach grades; stairways of 13 feet rise instead of 28 feet, as in the case of the elevated loop; simplified the handling of the baggage; improved the appearance of the main floor; and overcame all trouble from smoke and steam from locomotives.

The one very important thing that was thus accomplished was the making of the great terminal a through station for one kind of service, and a terminal station for the other. Suburban trains do not carry mail, express matter, or baggage in any quantity. They carry people only, and should be run frequently and be got

out of the way quickly. The through-station loop feature makes it possible to handle as many trains at the terminal as can be run over the main line. Moreover, as the new terminal must eventually provide for suburban trains from four main lines—the Boston and Providence, Old Colony, New England, and Boston and Albany railroads—such trains must leave the station at shorter intervals than trains could be run on either main line alone. This is accomplished by providing two loop tracks, arranged with a minimum number of switches, to be used alternately, each track being capable of holding several trains.

The separation of platform levels, thus accomplished, still made special provisions necessary for the expeditious and safe handling of baggage. Nine baggage and express trucking platforms running the entire length of the train shed, independent of the passenger platforms, were provided, and an underground passage was designed to allow the baggage trucks to cross beneath the tracks.

The civil engineering was well developed along these lines under the direction of Mr. Francis, and a head house designed by the architects, Messrs. Shepley, Rutan & Coolidge, of Boston, when an opportunity was afforded Westinghouse, Church, Kerr & Co., acting on behalf of the various Westinghouse interests, to consider the engineering requirements of the terminal other than embraced in the track and structural work, and to prepare plans and specifications for a complete mechanical installation.

The accompanying reproduction of a general plan of the property (Fig. 156) shows the prominent features of the terminal so far as determined at that time. This drawing shows the arrangement of tracks and buildings in the yard necessary for the safe and expeditious handling of trains. In all, about 750 trains have been transferred to the new station, involving daily something over 4,000 movements through the switches in 18 hours.

The specific problem presented involved the detail design of a complete equipment most suitable to the needs and uses of this large railway terminal. Such an equipment was considered to be a means to an end rather than an end in itself; and in all things due regard was had to the fact that a railroad terminal, rather than a mechanical equipment, was to be built and operated. As a result, many things were done that would not have been, had the conditions and requirements of the terminal, from a railroad standpoint, been different.

In connection with the work, careful investigations were made

of the features and needs of other important railroad terminals in this country and abroad, a vast amount of data and information of a valuable nature was accumulated and used so far as available; but by reason of the great size of the new station, and particularly the unique character of some of its prominent features, many problems were presented of a kind not heretofore met in such work.

The solution of the problem which was finally presented embraced the following principal items:

1. The complete installation of an electro-pneumatic system of switching and signalling.
2. A power-house equipment.
3. An electric wiring installation for arc and incandescent lighting, and for electric power for various uses.
4. Passenger and freight elevators, baggage and express lifts.
5. Apparatus for warming and ventilating the head house, and heating yard and express buildings.
6. Ice-making plant to supply ice for cars, restaurants, etc.
7. Refrigeration for restaurant, kitchen and storage boxes, and flower booth.
8. Filtering and water cooling plant to furnish supply of drinking water.
9. Car heating in train shed, storage, and express yards.
10. Compressed air supply for charging and testing train brakes.
11. Fire protection for the various buildings and train shed roof.
12. Disposal of storm water and drainage from waterproofed structure.
13. Frost protection for roof conductors.
14. Steam and hot water supply for head house.

The substantial gains in simplicity, first cost, and in operating expense possible with the opportunity to design this complete engineering equipment in which many kinds of service are involved, each of which was considered merely a branch of one comprehensive system, are known to have been very large. They followed in a larger measure, because of the opportunities provided at an early period to harmonize conditions and details of other construction with the requirements of the entire system, and to remove obstacles to the employment of the most suitable apparatus and methods.

FIG. 157.—JUNCTION OF MAIN AND TRANSVERSE SUBWAYS AT POWER HOUSE, NEAR CENTRAL HEATING PLANT.

FIG. 158.—JUNCTION OF MAIN SUBWAY FROM POWER HOUSE WITH DORCHESTER AVENUE BAGGAGE WING BASEMENT. THE PROMINENT PIPE IS THE 8-INCH HOT WATER FLOW MAIN FOR HEATING PLANT

Thus, while the intrinsic merits of any piece of apparatus were always given due weight, it was possible, where other things were equal or nearly so, to allow considerations of adaptability to the general system to determine a choice, and in this way to simplify the whole to a great degree. Simplicity in general design, and few kinds of service, not only led to an averaging of the various demands on the source of power, thereby improving conditions and reducing the capacity necessary to provide, but manifestly led to a reduced cost of attention and skill required for operation and maintenance.

In general, it may be said that the several items of work which have been mentioned are all provided from a centralized system derived from a central power plant generating but one pressure of steam, and involve only the following classes of service:

1. Electric current on a uniform system wherever used.
2. Water distribution under simple conditions.
3. Air and ammonia compression.

The good results following this kind of treatment are very marked as compared with those obtained where little or no regard has been paid to general considerations of suitability, and specific instances are not wanting to forcibly illustrate the difference.

In the general design the problem of distribution was an important one. The territory to be served was large, the buildings long and narrow, and virtually cut in two by the presence of waterproofing at the main suburban exit, by the loop tracks, and by prohibitions placed upon carrying pipes over the main waiting room. The existence of this restricting "throat," as it was called, tended to complicate the already difficult problem of conveying light, heat, refrigeration, fresh air, power, and other service in the large quantities required at points far distant from the only available site for power house without excessive costs, and without employing conduits of almost impracticable dimensions. The further desire not to allow such obstructions to detrimentally affect the selection of apparatus and methods best adapted to the perfecting of a complete system, together with other considerations of an important nature, led to the use of some unusual features of design. Many of these would not have been possible at a later period in the undertaking, when facilities could not be easily created and obstacles readily overcome.

In general, loop circuits were employed wherever this could advantageously be done. The "main" and "transverse" subways

shown on drawing, were provided especially for this purpose, and made this possible. Other circuits were advantageously divided, with branches distributing through the main and transverse subways. In this way sizes and costs were greatly reduced, the required means much simplified, and the narrow throat (indicated by subway *S.D.*) made adequate, although only a comparatively few inches in its greatest allowable transverse dimensions.

The greatest latitude was also secured in the selection of apparatus, and important economies both of first cost and of operating expense made possible. The use of a heating system employing rapidly circulating hot water as a distributing medium effected large savings in cost, and enabled the varying quantities of exhaust steam—a waste product of another portion of the general system—to be stored and utilized to a greater degree than possible by any other method, besides avoiding the complications incident to the handling of drips in the waterproofed portions of the property below sewers, high water, and boilers. Thus, also, the use of electricity for operating the 24 elevators and baggage lifts avoided the introduction of a system of hydraulic machinery which, under the conditions prevailing at the terminal, would have been costly and somewhat complicated.

The opportunity to use a loop-feeder circuit for the elevator machines enabled power to be supplied in a manner calculated to allow the current flow to "average," and to secure the largest benefits from the inter-operation of the several machines.

These and other features of the installation will be mentioned more at length in the descriptions which follow. Allusion is made to them here for the purpose of pointing out and emphasizing the fact that, although much care and time were necessarily devoted to perfecting all details of the plant, that the best thought and endeavor were put on the fundamental design of the entire system considered as an operative whole. The engineering importance of this cannot be overestimated. It is only in connection with such treatment that skill in detail design can produce the best possible results.

Power House.

The general arrangement of the power house (Fig. 160) was determined by important considerations of track facilities and traffic requirements, leading to what some one has aptly termed a

FIG. 159.—POWER PLANT BUILDING. ICE PLANT LOCATED IN LEFT-HAND END. STACK SHOWS AT RIGHT OF VIEW. ONE OF THE SIGNAL BRIDGES IN FOREGROUND.

"tandem layout." It was evolved from a series of designs superior from an engineering standpoint, but less well adapted to fulfil all conditions or meet certain restrictions which were imposed. This form of plant was therefore determined upon only after full consideration of the many factors bearing on the work.

In designing this plant the fact was kept strongly in mind that the expense, including interest on investment, of operating the daily service of so large a terminal would be very heavy, with no opportunity for earning. It was therefore imperative that it should operate with a high commercial efficiency, and that it should be of a simple type and design, with minimum cost of attendance. The conditions did not permit economy to be sought through the use of abnormal pressures, complicated machinery, or extreme refinements.

The principal apparatus is contained in a well-lighted and well-ventilated brick building erected especially for the purpose, occupying a space 460 feet long and 40 feet wide on the easterly side of the yard. The plant furnishes power, light, heat, and refrigeration wherever required throughout the premises, and is the source of all the mechanical service that the terminal requires. So far as possible, precautions have been taken against accidental interruption of the service, and substantial relay has been provided throughout, either by the use of complete "spares," or through a choice of units which permits the loss of the use of one without impairment of service.

The boilers are set in one battery, and are of the horizontal return tubular type 72 inches in diameter, measured on the outside of the small course. There are 10 in all, and each contains 130 three-inch tubes 18 feet long. The shell plates are $\frac{1}{2}$ inch thick, rolled from a special quality of acid open hearth fire box steel. The heads are of acid open hearth flange steel $\frac{9}{16}$ inch thick. All material entering into the boilers was made to special specifications, and was required to meet rigid tests before acceptance. The longitudinal seams have quadruple riveted butt joints arranged to come above the fire line, and boilers are designed for a working pressure of 145 pounds per square inch. The use of this type of boiler was determined by considerations in which there was full acquiescence, but which would not necessarily have a bearing on other similar work.

The boilers are suspended from 8-inch I beams securely fastened together, and arranged in pairs so that suspender bolts

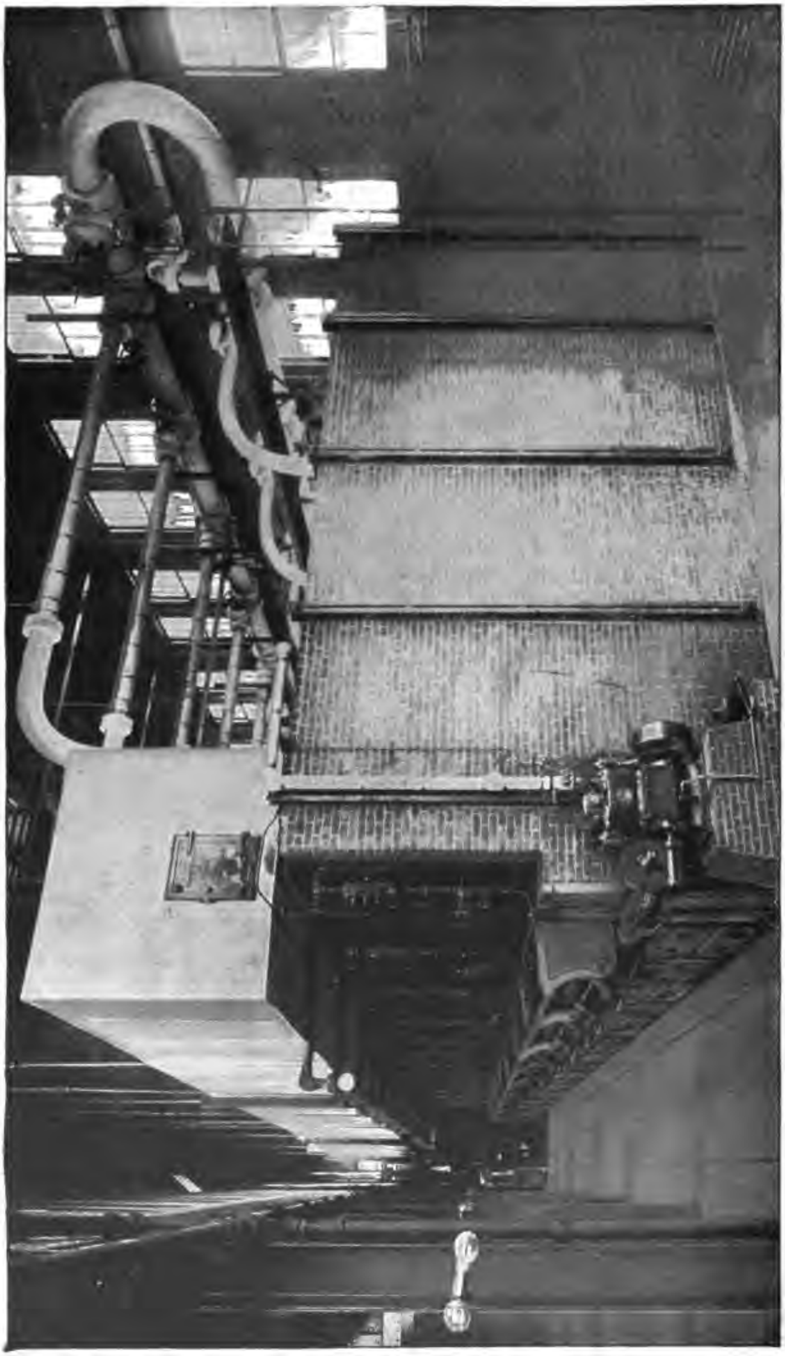

FIG. 161.—VIEW OF BOILER ROOM, SHOWING RONEY MECHANICAL STOKERS.

pass between the beams. The settings are lined with fire-brick throughout, and tops of boilers are covered with 2 inches of asbestos fire felt and asbestos cement.

The boiler plant is provided with an equipment of Roney Mechanical Stokers and Smokeless Furnaces (Fig. 161) adapted to burn widely different qualities of fuels, including anthracite or bituminous coals, "front ends" from locomotives, or various mixtures with the highest economy, without change of grates and without smoke. These stokers are the labor savers in the boiler room, and effect also a material saving in fuel.

The use of coal and ash-handling machinery was fully considered. This problem was complicated by the fact that much heavy construction beyond the power house was in such an incomplete state that no immediate provision could be made for handling water coal or to arrange for the future handling of rail and water coal indiscriminately. Several plans were devised which met all conditions satisfactorily; but for reasons which have no engineering interest, the installation of coal-handling machinery was deferred. Changes afterwards found necessary in the boiler-house structure seriously interfere with the full benefits to be derived from the present use of such apparatus. An inexpensive and satisfactory expedient for handling coal from cars to stoker hoppers was, however, devised and reasonable emergency storage provided. This arrangement consists of an overhead track capable of holding a loaded coal train, and arranged for dumping coal through scuttles to a false deck on a level with stoker hoppers, or through traps to the floor of the boiler house according as it may be desired for immediate use or storage.

The waste gases from the furnaces are conveyed through a suitable flue of heavy steel plate with angle-iron stiffeners, and covered with 2 inches of asbestos fire felt and cement, to a pair of improved circulating economizers of the form developed by the engineers. These economizers are provided with necessary dampers and by-pass, the arrangement being such that economizers may be used singly, in parallel, or in series with each other as the conditions of service may allow, thereby permitting the greatest possible savings to be made at all times.

The products of combustion are cooled by the economizers to a point at which natural draught could not be employed, except by the use of a chimney so high that its cost and the cost of its foundation would be prohibitive.

FIG. 162.—VIEW LOOKING TOWARD MECHANICAL DRAFT PLANT FROM TOP OF BOILERS. ECONOMIZERS AND FEED PIPING IN FOREGROUND.

Draft is furnished by a pair of large, slow-running fans, either of which is of sufficient capacity for an ultimate installation of five more boilers in addition to the ten now installed. Provision is made in the boiler room and in the design of the machinery for this additional equipment. The fans have "three-quarter" housings and vertical discharge, and are proportioned and designed in detail to meet the special service demanded of them in furnishing draught for steam boilers. Their wheels are of special construction and proportions, and are carried on heavy forged steel shafts running in water-jacketed boxes, the wheel shafts being connected to engine shafts by marine couplings. The engines are horizontal. One engine and its fan always lie idle as spare, dampers being provided so that either fan may be operated at will. Regulation is controlled by variation in steam pressure, the arrangement being such that a uniform pressure of steam is maintained in boilers by control of draft through regulation of fan speed.

The waste gases are discharged from the fans through a self-supporting iron stack 11 feet in diameter, and extending but a few feet above the power-house roof.

The feed pumps are in duplicate, and their steam ends are compounded. The water ends have outside packed plungers. The discharge is carried to economizers, auxiliary feed-water heater, and boilers in such a way that the heater, either or both economizers, or any boilers may be by-passed or used at will.

All hot feed water piping is of brass, the largest being 4½ inches diameter. The boiler blow-offs are 3 inches in diameter and are carried to a suitably vented blow-off tank with the ordinary connection to sewer. Each blow-off is provided with a gate guard valve and an angle blow-off valve, both extra heavy.

Steam is conveyed from the boiler house to the engine room and ice plant through a line of 12-inch piping arranged in form of a loop, the arrangement being such as to avoid the complexity usually accompanying a duplicate system of piping; at the same time permitting the isolation and repair of any part without impairment of service. All flanges on the principal live-steam mains are steel and are welded to the pipe. All fittings are cast iron, extra heavy. Long bends of iron pipe are used wherever turns are made, except in two cases where it was necessary to use copper. No expansion joints are used anywhere in the plant, it

Fig. 163.—Piping over Boilers. Each Boiler has Two Connections with Supply Mains, one to each side of the Loop. All Flanges on this Piping are Welded Steel and all Joints are Covered. No Expansion Joints anywhere in the Plant. Economizer and Mechanical Draft Plant in Background.

FIG. 164.—MAIN LIVE-STEAM PIPING IN ENGINE-ROOM BASEMENT—FLANGES, WELDED STEEL; JOINTS COVERED.

FIG. 165.—VIEW IN ENGINE ROOM DURING CONSTRUCTION.

having been possible to design this system of piping in a manner to make their use unnecessary. The miscellaneous service requiring live steam and auxiliary apparatus is supplied by a system of auxiliary piping having its origin in both sides of the main loop, but otherwise independent of it. Particular attention was paid to the design of the live-steam piping in power house with reference to handling water of condensation, and steam loops have been provided for returning such water automatically to the boilers.

Steam is carried directly from the steam main through large radius bends to each of the main engines. The initial installation consists of four engines of the Westinghouse compound single-acting type. The nature of the service at the terminal is such that loads on these main engines vary greatly from hour to hour, day to day, and season to season. At times use can be made of even more exhaust steam than the engines yield; at other times there is a surplus which is condensed in vacuum. The conditions were therefore not favorable to the use of receiver types of compound engines, although an indefinite tendency to prefer Corliss engines, and a willingness on the part of the engineers to use them, led to a full consideration of their capacity for saving under the conditions which existed.

To this end all the engine loads throughout the twenty-four hours of a day were carefully charted for every month of the year, and curves were plotted to represent corresponding quantities of exhaust steam required for heating. The number of pounds of water exhausted per hour by the engines of each type, when carrying the charted load, was used to plot curves of exhaust steam available for heating purposes. The Corliss type of engine was credited, without regard to the effect of variable loads, with the lowest water rate claimed by its makers at point of greatest steady load economy. The only times when steam would be wasted and an opportunity to save would exist would be when the exhaust exceeded the heating requirements, due allowance being made for the value of the heat-storage capacity of the body of water in the heating system. The three accompanying plates are typical of the twelve charts that were prepared, and illustrate the method of determination employed, each load being carefully considered and separately plotted. The possible saving was the difference in the amount of steam exhausted to atmosphere (or condenser) by the two types of engines, in excess of the amount

FIG. 166.—STEAM AND EXHAUST PIPING IN ENGINE-ROOM BASEMENT.

FIG 166.—STEAM AND EXHAUST PIPING IN ENGINE-ROOM BASEMENT.

required for heating. This was determined for each month in the year, and the amount of saving so calculated showed the amount in dollars to be insignificant as compared with the considerable additional expense involved.

Due consideration was necessarily given to the choice of units for the most economical and reliable performance of this work, and four 18″ and 30″ by 16″ engines, aggregating 1,500 nominal indicated horse-power were used, each being direct-connected to a 225-kilowatt engine type generator. The engine shafts are extended to take the generator armatures, and are provided with outboard bearings, the complete generating units being mounted on heavy cast-iron bedplates. Each engine can be run either condensing or non-condensing; the exhaust piping being so arranged that this can be done at will while engines are running.

The vacuum side of system is connected with a Deane independent steam condenser located in pit in engine-room basement. The atmospheric side of system connects with central heating plant of the heating and ventilating system, and free exhaust is provided through an 18-inch relief valve. This main exhaust system also receives the exhaust steam from all other sources in the plant.

A hand travelling crane, having a lifting capacity of 40,000 pounds, spans the plant, and is arranged to traverse the entire length of engine room and compressor room of ice plant.

Interlocking Switch and Signal System.

To thousands daily entering and leaving this largest of American railway terminals, its magnitude is represented by the great area of its train-shed floor; by the number and extent of the tracks laid thereon; by the proportions of the shed and head house, and by the incessant flow of humanity through its portals.

Comparatively few give more than a passing thought to the intricate track approach, and but few realize how utterly dependent is the punctuality of the station's traffic upon the arrangement of the tracks and the manner of their manipulation.

"All tracks look alike" to the average individual, and the ends, rather than the means of reaching them, generally interest him most. However far from public attention, and subordinate to other features this one may appear to be, it nevertheless is of the first importance to the station's management, and involves more

FIG. 170.—ENGINE ROOM IN POWER HOUSE.

dependency upon the part of its employees, than does any other of its departments. The magnitude of the station's plan; the manner of its execution; the capacity of its train shed and head house, together with the comforts and conveniences afforded the travelling public, are matters of interest only so long as punctuality marks the arrival and departure of trains. Punctuality of traffic would not have resulted if proper regard for the traffic's schedule had not been a potent factor in the design of the switch system handling it.

At the present time (October, 1899), 737 trains enter and leave the new station daily, 65 of these within an hour in several instances. Within the two minutes between 5:15 and 5:17 P.M., 6 trains depart and 3 arrive. The average train consumes one and one half minutes in passing from or to the station through this switch system. Evidently the nine trains mentioned must be passing through it at the same instant. Accommodation for nine simultaneous train movements is therefore essential to punctual service, and is necessarily a feature of the track arrangement for handling the schedule. Upon this track system *eleven* simultaneous movements may be made to or from the train-shed floor, while four additional movements may, at the same time, be made on the depressed tracks of the suburban loop system beneath it, making possible a total of fifteen simultaneous train movements.

Capacity for simultaneous train movements alone is, however, not the only requirement of a well designed track system; it is also important that means be provided for the direct movement of traffic from one track to another, and for the simultaneous execution of many such movements. It is further desirable that these facilities shall not involve special frogs and other appliances difficult of repair and renewal; that switches shall be so placed that they may be signalled comprehensively and in the simplest possible manner, and that they will occupy the minimum amount of space for the facilities they afford the traffic. The accompanying plan (Fig. 171) of these tracks shows how these requirements have been met in the design of the yard tracks.

When this plan is examined in connection with the statement made concerning train movements, the necessity for rapid and accurate manipulation of its switches is apparent.

Without some means of accomplishing this, and without a comprehensive system of signals working in conjunction with it, such

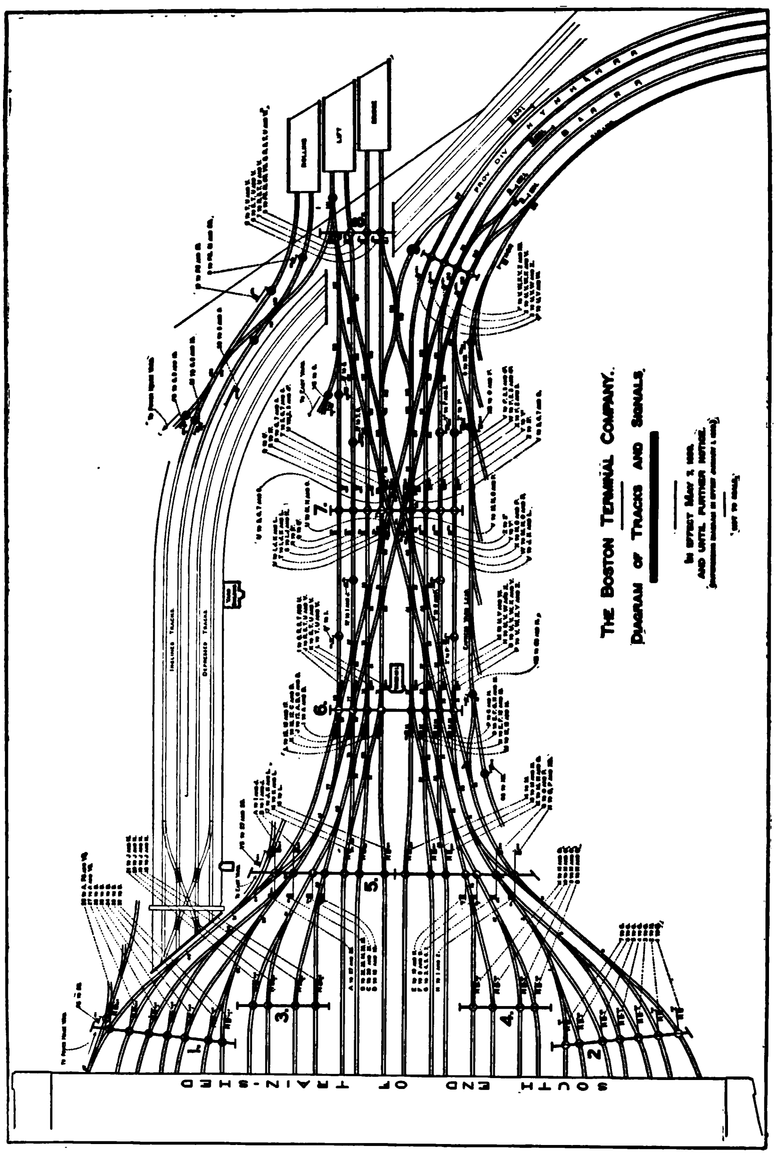

FIG. 171.—DIAGRAM OF TRACKS AND SIGNALS OPERATED FROM TOWER NO. 1, GIVING FUNCTIONS OF SIGNALS AND THEIR DESIGNATING NUMBERS. (REFER ALSO TO FIG. 153.)

a traffic would be in constant peril of derailment or of collision; hence the custom of placing fixed signals at suitable points throughout a switch system, and operating them from a central point by means of levers arranged in convenient proximity to like levers similarly connected to, and operating, the switches.

Two systems of interlocking were fully considered with regard to their application to the requirements at this terminal: the mechanical, and the electro-pneumatic. In both, the machine levers are so controlled one by another that signals cannot be given for trains to proceed until all switches in the route governed are first properly set and locked, and conversely so that the switches of a route governed by a signal cannot be moved during the display of a signal giving right of way over them.

Several plans were carefully prepared for both systems. The mechanical apparatus for the principal tower (No. 1) for working the switches and signals of the surface tracks in accordance with the best practice, would involve the use in it of about 360 levers, which, at the customary spacing (5-inch centres), would necessitate a tower at least 160 feet long. The lead-out for such a machine would occupy, if arranged in the usual manner, practically all of the space now devoted to the use of storage tracks, capable of holding 67 cars. Evidently such a sacrifice could not be made, and by way of demonstrating a means of avoiding it, the lead-out was arranged vertically along the wall of the subway, in one of the plans submitted. It involved the use of rocker shafts of such a length, that their construction, to avoid undue loss from torsion in them, would have been cumbersome and otherwise unsatisfactory.

A second plan for avoiding the sacrifice of the storage yard embraced an arrangement of the lead-out over the subway upon a deck supported by beams extending from one retaining wall to the other. This arrangement was also unsatisfactory; first, because it necessitated many jaws, cranks, and other connections which materially increased the already excessive loads put upon the levers (due to the heavy rails of the switches, and to the friction incidental to long connections between them and their operating levers); second, the objection to encumbering the subway with overhead structures outside of the station proper.

The plan involving the electro-pneumatic interlocking avoided these serious objections, and possessed desirable features which were of such vital importance that its adoption at this place

became almost a matter of necessity. The principal reasons that governed the decision may be summed up as follows:

In the mechanical system the levers employed are massive iron affairs connected to the switches by lines of 1-inch pipe suitably guided and deflected by roller bearings, bell cranks, etc., so that the motion imparted to the lever by its operator is transmitted directly to the switch.

Signals are similarly operated; wire frequently being used, however, as a substitute for the heavier pipe connections. The energy required to operate a switch by this means naturally varies greatly with varying conditions. The size of the rail from which the switch is made; the stroke of the switch; the length of the pipe line operating it; the alignment and lubrication of this line, and, finally, weather conditions, all influence the ease with which the levers of such an apparatus are shifted, and hence the ease with which the labor of the operator is accomplished.

The inability of an operator to shift by this means the load frequently permitted by traffic conditions to be attached to one lever oftentimes compels the use of several levers where one would be ample were his energies unlimited. Notwithstanding this subdivision of the work of one lever between several, the labor of shifting the levers of a mechanical apparatus is fatiguing in the extreme where much traffic is handled, and where this labor is, consequently, continuous for hours at a time.

A mechanical tower would be so large and its lead-out so extensive, that it would have to be at the side of the yard and so far from the central field of operation as to render a clear view from it of all the tracks impossible under many anticipated conditions. Not a small consideration, too, was that of the difficulties to be encountered in constructing permanently the leads of a mechanical plant on filled ground and under the adverse conditions presented for such work, during the progress of other construction work, interfering with these to a greater or lesser extent.

The pneumatic interlocking system, on the other hand, necessitated the use of only about one-third the number of levers required by the mechanical system, and a very much smaller force of men for its operation. By reason of the smaller number and closer concentration in its machine frame of the levers involved it required a tower of but one-fourth the length of that necessary for the mechanical system. It therefore permitted the location of tower No. 1 upon ground not required for other purposes, and

in a position giving the best view of the switches and signals operated.

Having no movable connections between the tower and the switches and signals, it involved no likelihood of interference with its operation from future settlement of the filled ground.

The number of levers employed in the pneumatic system is subject only to the restrictions imposed by traffic requirements upon the number of switches or signals that may be operated simultaneously from one lever. It does not involve that physical restriction, peculiar to the mechanical system, resulting from the natural limitations of an operator's energy and of the period through which he is capable of exerting it. In this connection it is interesting to note that instances are frequent in the Boston South Station interlocking plant where a single pneumatic lever operates a number of slip switches and movable frogs, their locking mechanisms and detector bars, that would require in a mechanical system four, and, in some cases, five levers for their operation.

The method of mounting the pneumatic signal lever permitted the operation from it of more signals than is practicable from a mechanical one. These levers have a central position normally, and are movable to the right and to the left of this position for working separately, but under the control of the locking, two or more signals governing conflicting routes.*

The first cost of a mechanical interlocking proved to be considerably greater than that of the electro-pneumatic, and the cost of operation and maintenance was found to be greatly in favor of the electro-pneumatic.

The amount of traffic handled by an interlocking does not bear any fixed ratio to the size of its interlocking machine, and one operator is occasionally able to handle an apparatus of 40 levers, that under other traffic conditions would prove burdensome to two.

While no general rule exists as to the number of men required for the operation of machines of various sizes, and though no rule will probably ever apply to this work in practice, an assumption was made that when the full limit of any interlocking is approached in the operation of trains through it, the assignment of more than 20 levers to a man is overtaxing his ability to stand for 8 consecutive hours the work to be performed. Hence the 360

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* Five or six signals are frequently operated by one lever in the Boston Terminal's interlocking.

levers that would be necessitated for the terminal interlocking, if of the mechanical type, would entail the employment of 18 levermen for their operation. The pneumatic system required but three. The hours of labor for each day being divided into three shifts of 8 hours each, two of these shifts required 3 levermen each, and the night shift 2, making a total of 8 levermen daily.

The mechanical plant, allowing 18 levermen for each of two shifts and but 6 for the night shifts, would employ 42 levermen daily. The average rate of pay at important places for levermen is about $75 per month. The 42 mechanical men would receive yearly $37,800; the 8 pneumatic men yearly $7,200; leaving a yearly balance in the latter's favor of $30,600.

The use of electricity as a controlling agent and of compressed air for actuating the mechanism of the electro-pneumatic system, entirely eliminated the question of distances in the problem of the operation of the switches and signals. Their use enabled the automatic control of signals by trains to be accomplished in a simple and reliable manner, and value was also attached to their flexibility. These and other important reasons led to the adoption of the Westinghouse electro-pneumatic system after mature consideration on the part of those having the matter in hand of all possible systems for the new terminal.

This system as installed, consists of the following elements: an engine for compressing air to the desired pressure and in the required volume; a receiving tank; a condenser and a pipe line extending to the extremities of the interlocked system of switches; a cylinder attached to, and adapted to operate, each switch and signal; an electro-magnetic valve mounted upon, and controlling the pressure from, the air main to each cylinder; electric wires extending from these magnets to the levers of the interlocking apparatus in the tower; an interlocking machine so constructed that the manipulation of its levers causes electric currents to be applied to or removed from the wires connecting with the valve magnets, and an electric generator for supplying the necessary current.

The air supply is derived from one or the other of two 14-inch by 18-inch Ingersoll-Sargent Piston-inlet Compressors (Fig. 172), alternation from one to the other being made every twelve hours.

Each compressor is capable of compressing 382 cubic feet of free air per minute at its maximum speed of 120 revolutions. Service at the Boston South Station rarely calls for a speed exceeding 30

revolutions, however, and the actual consumption of air by the interlocking during its busiest minutes probably does not exceed the equivalent of 100 cubic feet of free air.

Large reserve capacity is an important consideration at this and similar places, where a breakdown that exhausts the air from the pipe line and reservoirs would be attended with serious delays to trains if not rapidly repaired and the pressure quickly restored. For this reason, large compressors are employed.

In order that the moisture held in suspension by the superheated air, immediately after compression, may be precipitated at a point convenient of drainage and before it is passed into the service main, where in extreme cold it would prove troublesome, the air is conveyed from the receiving tank at the compressor through a system of manifold pipes of large surface area exposed to weather influence, and is thus brought to the temperature of the atmosphere again by radiation, the effect being to precipitate much of the moisture into a reservoir suitably arranged to receive it and provided with a blow-off for expelling it periodically.

At each switch and signal cylinder is placed a small auxiliary reservoir connected with the service main and the switch or signal valve in such a manner that the air, drawn from the main during operation of these devices, passes through the reservoir and deposits therein whatever sediment or remaining moisture it may contain after having passed through the condenser.

The air pressure employed in the system is about 80 pounds per square inch, thus permitting of small piston and pipe areas, compactness of operating mechanisms, and economical transmission of the air through long distances.

There are three interlocking towers in the terminal installation—one for the approaches, one for the suburban loop tracks, and a third for the terminal yard. The main tower (No. 1) is the one of chief interest, and is situated on the centre line of the terminal, midway in its switch system. The interlocking apparatus is located in the building, and comprises 130 levers for operating 91 high home signals, 36 cautionary signals, 21 dwarf signals, 31 double slips with movable frogs, and 49 single turnouts; which represent a total of 148 signals, and the equivalent of 233 single switches.

The switches and signals of the suburban tracks are located at their entrance to the head house, under the train-shed floor, and being simple and few in number, possess no special feature of

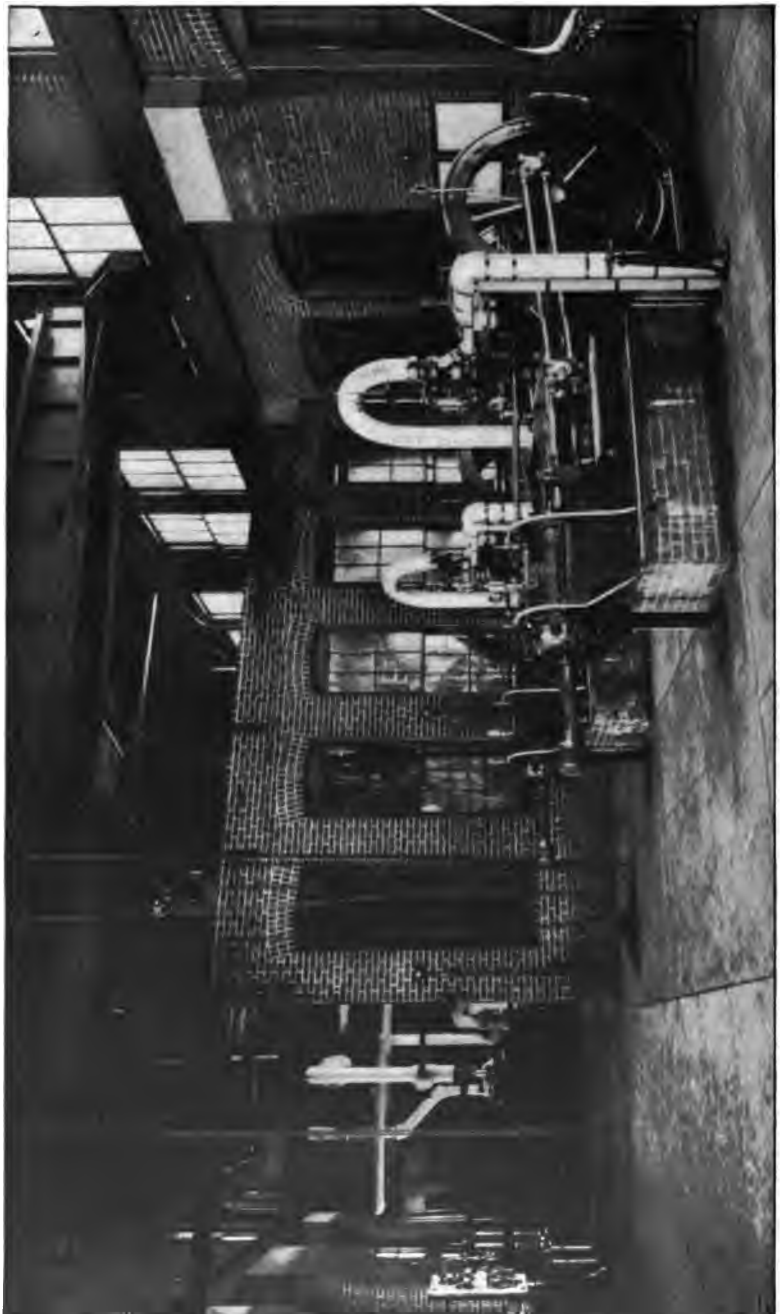


FIG. 172.—PAIR OF INGERSOLL-SARGENT AIR COMPRESSORS, LOCATED IN MAIN ENGINE ROOM, FOR SUPPLYING COMPRESSED AIR TO THE ELECTRO-PNEUMATIC INTERLOCKING SWITCH AND SIGNAL SYSTEM. ICE PLANT AT REAR OF VIEW.

interest not also common to the larger system on the surface, except that they are operated from an independent tower known as No. 2, and by a distinctly separate apparatus from those of the surface system. This tower is located on the west subway retaining wall, immediately opposite the switches handled from it, and the interlocking apparatus therein contains 10 working levers and 1 spare lever, the former operating 4 double slip switches with movable frogs, 4 single turnouts, and 8 dwarf signals.

The machines for all the towers are alike in principle, and are provided with two types of levers—one for the operation of switches, and one for the operation of signals; the handles of the former standing somewhat above those of the latter. Each lever is adapted to rotate a shaft extending from it to the rear of the machine through an arc of 60 degrees, and by these shafts the several functions of the apparatus are performed.

The forward ends of these shafts lie under and at right angles to a series of bars extending from end to end of the machine. In each of these bars a rack is cut which engages a segmental pinion keyed to one of the shafts, so that the partial rotation of the shaft by its lever produces a longitudinal motion of the bar engaging it. Metal "dogs," which give motion to smaller and shorter bars suitably guided at right angles to and above them, are mounted upon these bars. These engage or disengage the dogs of other bars, and thus prevent or permit their operation, and consequently govern the movements of their operating levers.

It is this mechanism that constitutes the "interlocking" of the apparatus, and renders such vital service to the operator in preventing serious results accompanying errors or oversights on his part during his manipulation of its levers.

Back of this "locking bed" lies a hard rubber plate over which the shafts also extend. The shafts here are covered with hard rubber tubing carrying metal bands that extend partially around them, and which are arranged (when the lever is moved) to form or to sever metallic connections between metal strips that are mounted upon the rubber plate immediately under them—these strips constituting parts of the various electric circuits controlling the valves of the switches and signals operated. The circuit of each valve may be thus controlled by any one or all of the levers in the machine as circumstances may require.

To the rear of this rubber plate and supported by the machine frame, immediately under and engaging the extremities of the

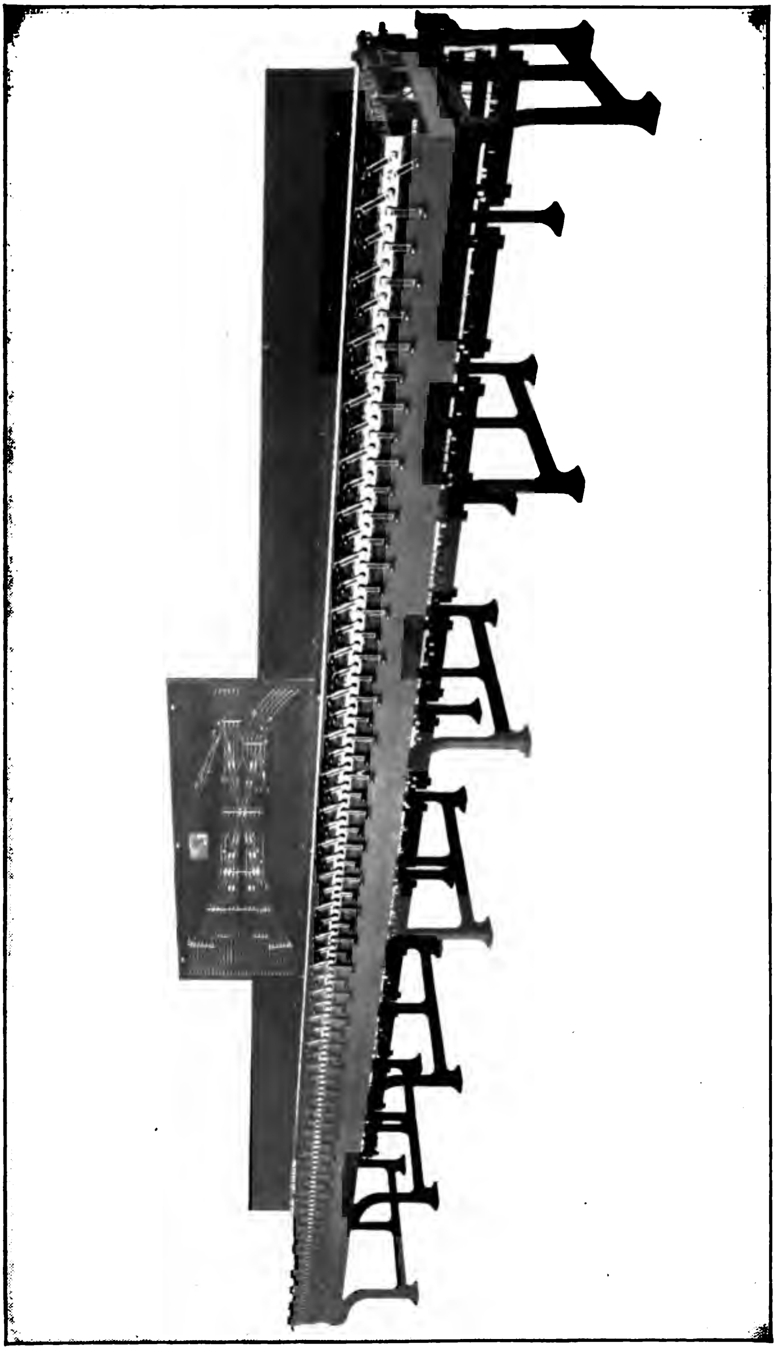


FIG. 178.—FRONT VIEW OF INTERLOCKING MACHINE IN TOWER NO. 1. OPERATING MORE SIGNALS AND SWITCHES FROM A SINGLE POINT THAN IS DONE BY ANY OTHER APPARATUS IN THE WORLD.

shafts, are two rows of electro-magnets. These magnets are controlled by motion and position of the switch or signal operated from the lever engaged by each, and are designed to insure that the lever and switch or signal shall coincide in position before the lever can be given its full movement—which movement is essential to the display of any signal giving right of way through the interlocking.

Electric current for the system is provided by a duplicate set of chloride accumulators of 300 ampere-hours capacity, that is charged from a rotary transformer driven by current from the main power house, and which delivers to the batteries 20 amperes or less, at an electromotive force of 25 volts, as required. The maximum output of the batteries for all purposes is about 5 amperes for the interlocking at the new South Station—the 6 cells maintaining a minimum potential of 12 volts at the interlocking machine.

The medium by which the switches and signals are moved by their respective levers in this system has not the power, of itself alone, to detect failure of the former to respond to the latter, and obstructions in switch points or incomplete movements of switches or signals from other causes might, if not detected with certainty, result in serious derailments or collisions; hence the necessity for these precautionary provisions.

A characteristic feature of the pneumatic interlocking machine is the "track model." Mounted vertically over the machine frame is a black metal board upon which a miniature model of all tracks operated is formed of light brass strips. The switches of this model move in harmony with those on the ground, and at all times correctly represent the actual track connections within the interlocked territory.

The number of signals required for an interlocking system is determined largely by the extent of territory covered by its tracks and by the frequency and nature of the train movements made over them. Considering safety alone, the minimum number of signals essential to the protection of any switching plant is represented usually by the number of tracks upon which trains may enter it. When the territory covered is small, or when the traffic is light or composed wholly of "through" movements, as at grade crossings and junctions, the minimum number is usually ample. Where movements are not all "through;" where the track system is of large area, and where many movements are involved, neces-

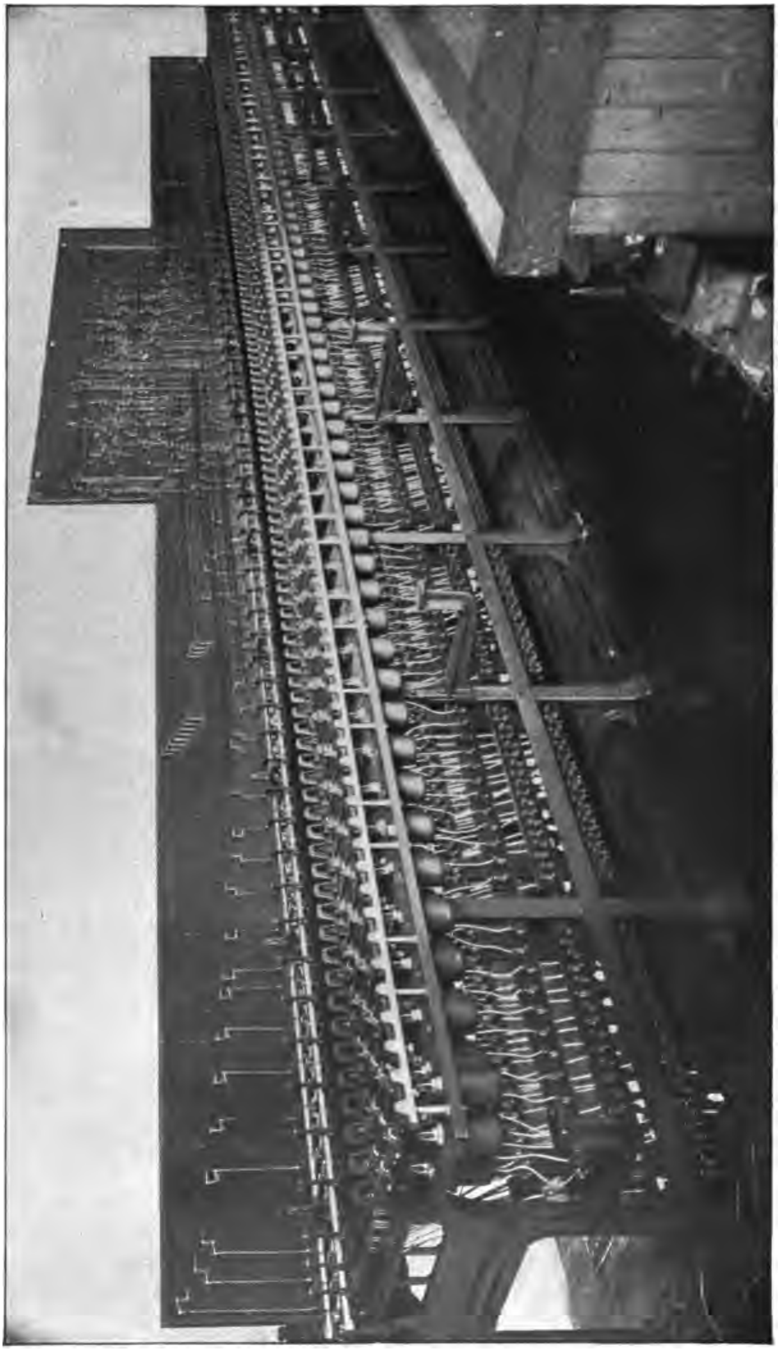


FIG. 174.—REAR VIEW OF ELECTRO-PNEUMATIC INTERLOCKING MACHINE IN TOWER NO. 1 (CABINET REMOVED).

sitating frequent and rapid shifting of trains and engines, as at this large terminal station, many additional signals are necessary to insure expeditious service; hence the large number employed.

Of these signals, 128 are mounted upon 9 iron truss bridges spanning the tracks governed by them. All are mounted on iron posts, and conform to the New York, New Haven and Hartford standard with respect to form, position, and color, which, by virtue of a recent decision, involves the use at night of a red light for danger, a yellow one for caution, and a green one for safety. Below each of 28 signals, which govern trains starting from the station, there is a distant signal, which, when cleared, indicates that all advance home signals of the routes governed by them are also at "clear." There are also 8 cautionary signals to govern trains in-bound to the station.

Trains automatically control the latter by rail circuits formed of the tracks from the bumping posts within the shed to their points of intersection without the shed, and they move to safety with the home signals above them only when the shed tracks are unoccupied. The failure of one to thus move with the signal above it is an indication to an approaching engineer that the track he is about to enter is already partially occupied, and that he must enter it cautiously.

Each signal is so constructed that it rests by gravity in the danger position; hence a *single*-acting cylinder only is required to shift it. This cylinder is of 3 inches diameter and 4 inches stroke, producing an energy, with 80 pounds of air, equal to the elevation of about 187 pounds one foot, thus permitting the use of a counterweight sufficiently heavy to insure certainty of the signal's return to danger under the most unfavorable weather conditions.

In the "dwarf" signal, where heavy counterweights are inconsistent with compactness of design (an essential feature of this type), a stout coil spring is substituted for gravity to a great degree.

The small volume of air used to move these signals is controlled by a valve under the control of an electro-magnet. These valves are of the "pin" variety, and are readily shifted by the energy of the magnet above them. When the magnet is de-energized, the combined influences of the pressure and a coil spring under the admission valve hold the latter seated and the exhaust valve above it open, thus permitting the free exit of pressure from the cylinder in ordinary operation, and also preventing its ac-

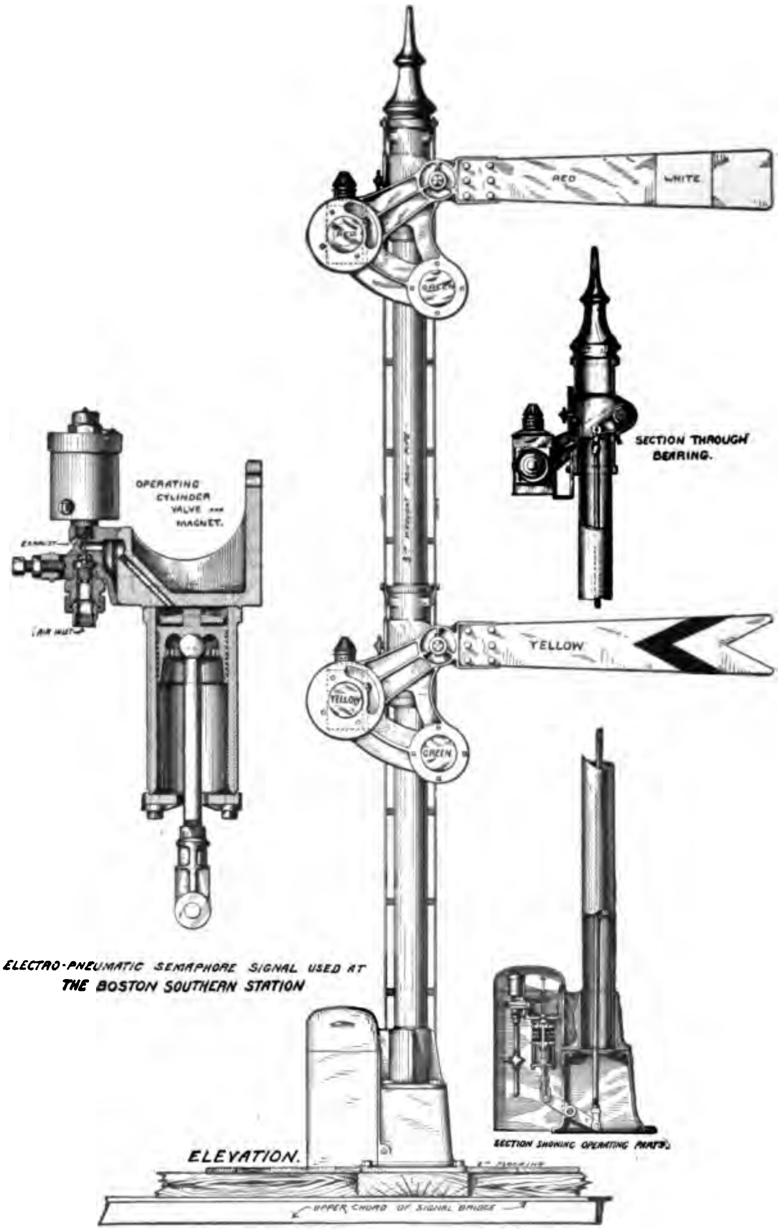


Fig. 175.—Two-armed Electro-pneumatic Semaphore Signal, Showing Operating Mechanism and Internal Connections (For Use on Signal Bridges).

cumulation therein should a leak develop in the admission valve. When the magnet is energized, the exhaust is closed and the pressure is admitted to the cylinder, whereupon the piston, overcoming the signal's counterweight, moves the signal to the safety position.

On each signal movement, so arranged as to be opened the instant the signal moves from the danger position, is a pair of contact springs controlling a circuit extending to, and including, an electro-magnet actuating a lock engaging the signal lever.

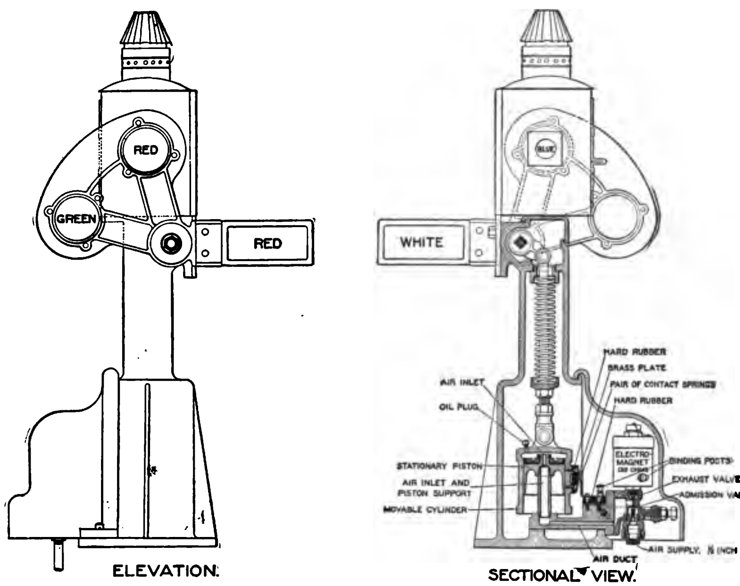


FIG. 176.—ELECTRO-PNEUMATIC DWARF SIGNAL FOR "DRILL" OR "SHUNT" MOVEMENTS, SHOWING OPERATING MECHANISM.

Each lever, upon moving a signal to safety, thus becomes electrically locked by the signal itself, and cannot be completely returned to normal until the signal has returned to danger. This is effected by a *partial* movement of the lever toward normal, the lock being so applied as to permit of this with the signal at safety. Any failure of a signal to return to danger thus prevents the return of its operating lever to normal, and until this is effected the switches governed by the signal cannot be moved.

Signals are designed to return to danger by gravity, not for simplicity's sake, nor for any convenience the method may entail in their operation; but are so designed to secure the greatest degree

of safety to traffic during an abnormal condition of them or their operating connections. Gravity, being a force that can be invariably relied upon, is used to hold the signal at danger when any one or all other forces employed for its operation are rendered inactive.

The failure of a signal to move to safety when safety exists may produce delay, but nothing more serious; to fail to move to

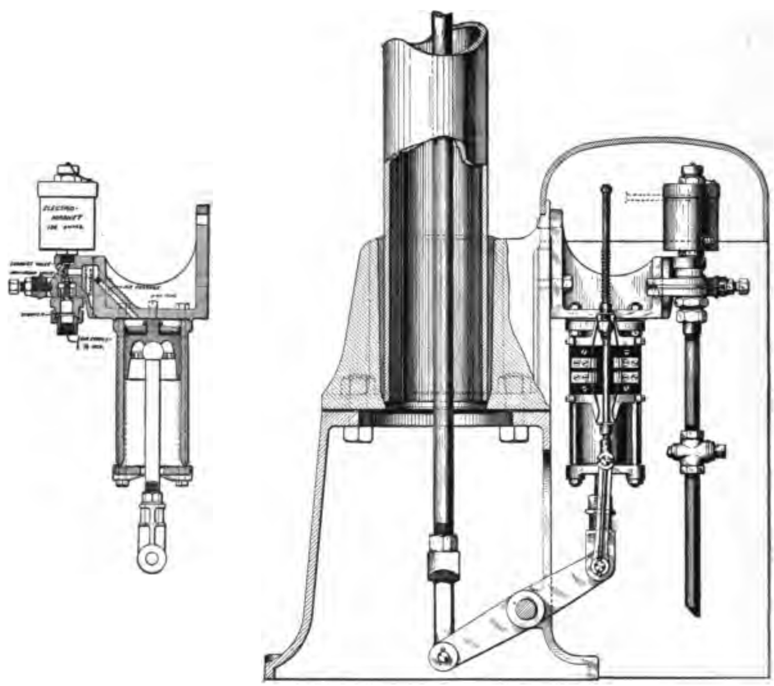


FIG. 177.—ENLARGED VIEW OF OPERATING MECHANISM FOR ELECTRO-PNEUMATIC SEMAPHORE SIGNAL.

danger when danger exists is a vastly more serious matter. The same reasons, or equally good ones, do not apply to the retention of switches in one position by gravity, nor is the attempt made to so operate them, for this and for obvious other reasons; hence the cylinders operating them are *double* acting, and they are consequently equipped with two magnetic valves, one at each end.

The comparatively large volume of air used by a switch cylinder (6-inch diameter, 8-inch stroke) is, however, not so readily or so quickly handled by the pin valves (before mentioned as operated

by electro-magnets and as controlling directly the pressure to signal cylinders), and those employed for switch operation, therefore, are arranged to control the pressure to the switch cylinders *indirectly*. They control the motion of two small auxiliary cylinders secured to the side of the switch cylinder, which have mounted between their piston ends a slide valve of the usual steam-engine type, which readily admits and discharges the greater volume of air used by these cylinders.

A bolt locked to the slide valve is made a feature of the design. The lock consists of a plunger applied normally by a stout spring to a recess in the slide valve, and which is withdrawn by exhausting the air from above the plunger by means of a third magnetic pin valve, thus permitting the full pressure in the valve chamber to overcome the spring and force out the bolt. When the magnet is de-energized, the exhaust-pin valve is closed, and the pressure, by passing through a small hole drilled through the plunger's piston, gradually balances the latter and permits the action of the spring to again lock the slide valve.

In operation this lock must be withdrawn before an attempt to shift the slide valve will be successful, and the electric contacts of the switch lever are so arranged that the three magnetic valves of the switch mechanism are operated in proper sequence to withdraw the plunger previous to each attempt to shift the valve.

Whatever the provision for preventing unintentional operations of switch levers by levermen, the best of these are liable at some time or another to make the attempt and to succeed in spite of the precautions taken. To guard as far as possible against disaster accompanying such cases, switches are equipped with what are technically termed "detector bars." These are of a length equal to the wheel base of the longest car, and lie just below rail level against the outer sides of the stock rails of switches. They are mounted upon radial links pivoted in brackets secured to the rail flanges in such a manner that a longitudinal movement of the bars is also accompanied by an upward movement of them above rail level. The fore part of the bar's motion precedes the unlocking of the switch and any motion to the latter. A train standing or passing over a switch prevents motion being given the bar, and hence protects itself against derailment resulting from attempts to move the switch under it.

The Old Colony Railroad (now Plymouth Division, N. Y., N. H. & H.), whose former terminal was at Kneeland Street, near the

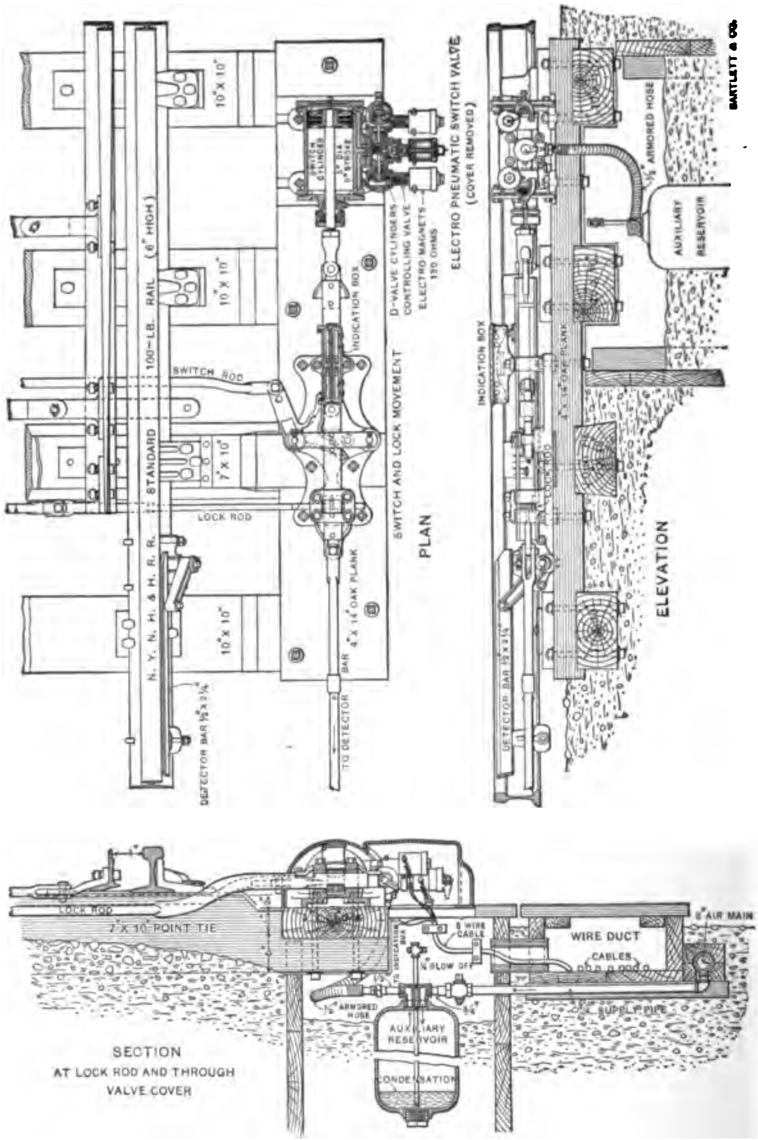


FIG. 178.—ELECTRO-PNEUMATIC OPERATING MECHANISM APPLIED TO A SIMPLE SWITCH.

south end of the new yard, and the New England Railroad (now Midland Division, N. Y., N. H. & H.), which formerly had its station on the site of the present head house, began using the new station on January 1, 1899, and to accommodate the 250 trains of these divisions a portion of the terminal's tracks was put in use on that day with switches and signals worked from a temporary pneumatic machine located in a temporary cabin near tower No. 1, the yard not being then sufficiently completed to admit of the erection of all the signals and connections of the final arrangement.

On May 7th, the permanent tower and machine were put into service, and a large part of the permanent interlocking was then ready to receive the 192 trains of the Boston & Albany Railroad, which entered the new station on July 23d, thus making a total of 444 trains using the station on that date.

On September 10th, the Providence Division of the N. Y., N. H. & H. R. R. transferred its traffic from the Park Square Station to the new station, and these trains swelled the total up to the present figures, 737 trains.

It was decided, shortly after the opening of the station to traffic, to divide its shed tracks into sections, assigning certain tracks to the B. & A. R. R. and others to each division of the N. Y., N. H. & H. R. R., rather than to attempt to operate one side of the station exclusively for inward and the other for outward trains, as was originally contemplated. This became almost a necessity for another reason: During the morning the shed is filled rapidly with incoming trains and in the evening by outgoing trains, which frequently occupy 80 per cent. of the station's tracks, and thus would encroach beyond a division line, were one drawn.

While the surface tracks of the new station permit of handling upon them more trains in a given time than is possible by the track arrangement of any other *terminal station* in this country, the added facilities presented by the suburban "loop" system beneath it gives it a capacity largely exceeding that of any other station in the world. The actual capacity of the loop system is as yet unproven, as its use is held in abeyance pending the solution of certain motive power problems affecting the traffic for which it is intended.

The capacity of the surface tracks is demonstrated, however, and though these tracks are as yet not all completed, and though much that is completed lies idle, pending the completion of two of

the three leaves of the drawbridge over Fort Point Channel, the heaviest summer traffic of the Consolidated and the Boston and Albany Railroad systems was handled with no inconvenience or delay upon that portion in use.

In addition to the usual telephone and telegraphic equipment and such annunciators as are used for announcing trains approaching the station, a set of 28 annunciators (one for each station track) is arranged in the bay of the tower, for the announcement by conductors of the readiness of trains to leave the station. At three points along each track within the shed special push buttons are provided for actuating these annunciators. Each conductor notifies the despatcher in the tower, and receives an acknowledgment, which is sent by act of restoring the annunciator drops. Above these annunciators is arranged a set of 28 indicators (one for each shed track), which are automatically actuated by trains within the shed by means of the rail circuits formed of the shed tracks, so that constant evidence is thus had of the presence or absence of cars upon any of these tracks.

Although the method of operating the station did not contemplate train movements being made except in the normal direction, provision is nevertheless made in the interlocking apparatus for such movements. Signals cannot be given for these movements, however, without the coöperation and consent of the director, who, when the lever combinations have been made for them, may clear the signals permitting them, by means of a magnetic key under his control. The leverman has the power to restore to danger the signals thus operated, but cannot, under any circumstances, move them to safety unassisted by the director. Such train movements should, in general, be prohibited; but owing to the large number of "shunts" or "drill" movements at this place, provision was made for them in the interlocking.

This provision naturally requires another in the signal system, which is to prevent the approach of trains towards the terminal, on the inward tracks, during outward movements upon them. These provisions being made, the maximum capacity of the station's tracks may be utilized in the event of emergencies without undue risk of collision between trains.

The plant is under the direct care of a supervisor of interlocking, who has charge of its operation and maintenance. The operating force consists of a directing despatcher and assistant, a telephone attendant, a telegraph operator, and three levermen.

The maintenance force consists of a general repairman and two assistants during the day and a repairman and helper during the night.

The yardmaster has direct charge of traffic, and has one or more assistants, as circumstances require. The maintenance of tracks is under a roadmaster of the terminal company.

The directing despatchers issue to the levermen orders for such manipulation of the interlocking apparatus as are necessary for the train movements to be made. The telephone attendant controls a switchboard connected with the various departments of the station proper and with the departments of the several roads using the station, while the telegraph operator has charge of all telegraphic communications, train reports, records of delays, failures, etc. The levermen manipulate the interlocking apparatus to permit the movement of traffic called for by the director. The directors and operators are located at the station end of the tower in a bay-window constructed so as to give opportunities for views of the tracks in all directions.

The interlocking machine occupies a floor area of 6 feet by 30 feet, and the tower a ground area of 14 feet by 42 feet. The hours of duty consist of three shifts of 8 hours each, and each man was the subject of careful investigation as to his fitness before his appointment to duty.

The Electric Plant.

The application of electricity to the service of the terminal comprised the following:

For incandescent lighting.........	650	horse-power	connected	load.
" arc lighting................	200	"	"	"
" general motor service	320	"	"	"
" elevators and baggage lifts....	381	"	"	"

This service was to be distributed over an area of approximately 1,100,000 square feet of floor space besides the yards, the maximum distance from the power house being about 3,000 feet. In addition to the foregoing, a very small amount of current was required for use in connection with the system of switches and signals, for operating clocks, etc. There were reasons why the alternating system could not be used; therefore, the problem to be solved involved a selection from among continuous-current types, the question of voltage, the number and size of units, and a suitable method of con-

trolling and distributing the current. A conception of the amount of electrical service to be rendered is had by noting that in arc lighting alone there are but three cities in Massachusetts outside of Boston and the municipalities contiguous thereto in which there are a greater number of municipal arc lights than those used by the terminal.

Considerations of floor space alone were almost sufficient to make necessary a universal system; *i. e.*, one in which all classes of service are supplied by the same generators, even if economy of first cost and of maintenance had not, as they did, also weighed in the same side of the scale.

A careful comparison of the conditions prevailing in other terminals made it possible to determine with close approximation the hourly demands of each class of electric service, and to construct therefrom superimposed load diagrams, showing the probable output of the generating plant for every hour of the day. On this information, due regard being had for other conditions, the unit selected was a 225-kilowatt Westinghouse generator, three being sufficient to handle present maximum loads and a fourth remaining as a relay.

Provision is also made for the addition of further units should increased service be required in the future. It was desired to secure the advantages of economy and of service afforded by the use of 110-volt incandescent lamps; also the low first cost for conductors and the good regulation permitted by the three-wire system, as well as the 220-volt motor service possible thereby. The small size and great number of the generating units required by this system as ordinarily installed, however, would have not only seriously increased the floor space as well as first cost of apparatus, and further very materially reduced the efficiency and increased the cost of maintenance, but would have necessitated anything but an ideal station arrangement. An ingenious method was therefore devised for constructing three-wire generators, each capable of supplying both 110 and 220-volt current at the same time. This method is used here in just this way for the first time.

In the ordinary three-wire system, two 110 to 125-volt generators are connected in series, and the three wires of the system are attached, the two outside ones to the extreme terminals of the machines, and the middle wire between them. One hundred and ten volt lamps are then connected between the middle and each of the outside wires, but the middle wire only carries current

FIG. 180.—INTERIOR OF ENGINE ROOM IN POWER HOUSE, SHOWING GENERATORS.

representing the difference between the load connected to the two sides of the system. When these two sides are evenly balanced, as it is always the aim to have them, no current at all flows on the middle wire, and the pressure of the system is 220 instead of 110 volts. This means that conductors of one-fourth the size will serve to distribute the energy with a given loss. The advantages of such a saving are sufficiently obvious, but the disadvantage, which is especially prominent in small installations, lies in the necessity of always running two machines, no matter how small the load may be. This means smaller sized units, lower efficiencies, greater first cost, larger floor space, etc. The Boston Terminal Company's machines practically reproduce the three-wire conditions, but condense each two small machines into one machine of twice the size. Of course, two machines might be built into one, by mounting two armatures on the same shaft and putting two sets of fields on the same frame. This, however, would be a change in name only, as the efficiency, number of parts to maintain, floor space, first cost, etc., would not be materially changed. Likewise, an attempt to put two windings on the same armature introduces difficulties, as, in the modern generator, every available inch of space is already utilized for winding. The plan adopted for the terminal machines was to make generators with standard windings to give 220 to 250 volts, and to connect the middle wire of the system to the middle or neutral points of these windings. This arrangement reproduces in effect practically all the features of the usual three-wire system, without, however, any of the disadvantages above mentioned. The method of accomplishing this middle connection is the novel feature of this machine installation, and is as follows:

Two leads are brought out from the rear of the armature winding 180 degrees apart, and are connected through collector rings to the terminals of a suitable stationary choking or balance coil surrounding an iron core. As the current from these leads has not passed through a commutator, it remains an alternating current, and the counter electromotive force set up in the choking coil balances the electromotive force of the generator, and prevents the flow of current. However, if the middle point of the coil be connected to the neutral wire of the three-wire system, the presence of an alternating current in the coil does not interfere with the otherwise free flow of the continuous current through the neutral wire, and the passsage into the armature

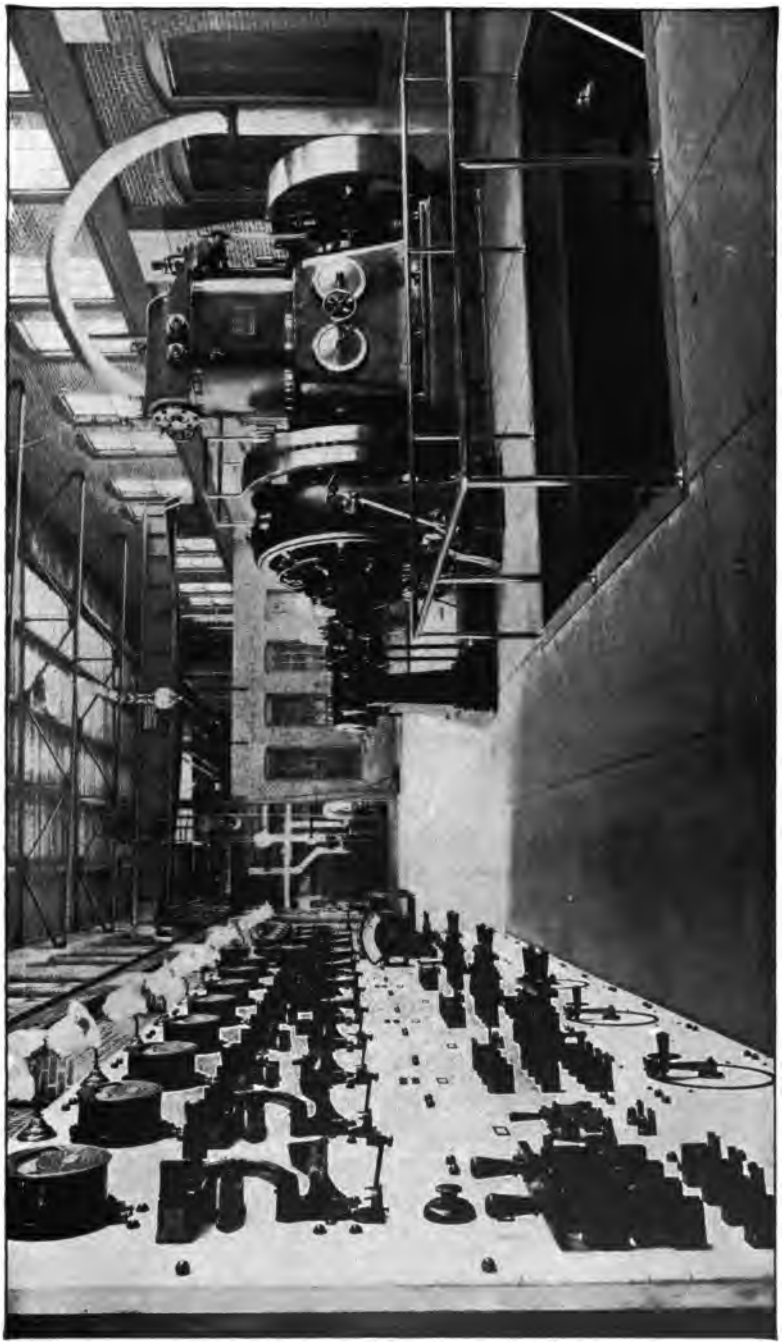


FIG. 181.—NO. 4 ENGINE AND GENERATOR. MAIN SWITCHBOARD AT LEFT OF VIEW. ICE PLANT AND TWENTY-TON TRAVELLING CRANE IN BACKGROUND. CONDENSER PIT SHOWS IN FOREGROUND.

through first one half of the coil, and then the other half, as the alternating current reverses its direction of flow. Where the difference between the loads of the two sides of the system is small the capacity of the balance coil may be correspondingly small, and as such is the case at the South Station, it is found that one moderate-sized pair of balance coils is sufficient for the entire system when all four generators are in service. This method provides, therefore, an opportunity for the best conditions of service outside the power plant, combined with the most economical and efficient arrangement within.

The four 225-kilowatt dynamos in the generating plant are of the multi-polar (10 poles) compound-wound type with fields vertically divided, and are mounted each on the extended shaft of a Westinghouse compound engine, the general arrangement being elsewhere described more in detail.

Generator cables are carried under the floor to the switchboard.

The main switchboard is complete and comprehensive, combining great flexibility and ease of control with simplicity. It consists of polished white marble panels placed side by side and containing the desired switching, indicating, and controlling appliances; those for the generators occupying one end, and those for the feeders the other, with load panel between, thus permitting the addition of either more generators or extra feeders in the future without disturbing the original board. All generators are arranged to run normally in multiple with each other; but in order to provide against the possible disturbance of the system by any one or more circuits, and to permit the greatest possible flexibility in operation, a second set of bus bars is provided, on which any machine or circuit or combination of machines and circuits may be thrown at will. An ammeter, a circuit breaker, and a field rheostat are connected to each generator.

The problem of the distribution and control of current was not a simple one. In its final solution it involved 18 feeder circuits connected to the main switchboard, and in general leading to corresponding distributing centres. These feeders are as follows:

Feeder No. 1. Public lights in head house.
" " 2. Basement lights in head house.
" " 3. Lights in restaurant, barber shop, etc.
" " 4. Inward baggage rooms, platform, and outside.
" " 5. Outward baggage rooms, platform, and outside.

Feeder No.	6.	Midway, train shed, front of building, and entrance.
" "	7.	Suburban platform.
" "	8.	General offices.
" "	9.	Suburban tunnel.
" "	10.	Express office and platforms.
" "	11.	Power house.
" "	12.	Interlocking towers and sump lighting.
" "	13.	Elevator motors.
" "	14.	Basement fans.
" "	15.	Attic fans.
" "	16.	Sump motors.
" "	17.	Signal lights.
" "	18.	Roll lift drawbridge motors.

At the terminus of each principal lighting feeder is a subsidiary switchboard mounted in a cabinet and kept under lock and key. The various distributing circuits are controlled from these secondary boards, and, so far as desirable, made independent of the power house attendants, although adequate provisions are made to compel full coöperation in the manipulation of the current.

This is accomplished by means of an annunciator system with push buttons at each distributing centre, and annunciator on load panel of main switchboard. Pilot lamps, installed on the distributing boards, show whether the boards are "dead" or "alive;" the normal condition being "dead." The push button is pressed when current is desired, and the pilot lamps show when the feeder switch on main board has been closed. This arrangement secures the very best of service, enables the operating force at the power house to take advantage of opportunities to shut down generating units when not needed, and makes it impossible to throw large loads on the power house without adequate notice. Pressure wires are run from each distributing centre to corresponding voltmeters on the main switchboard in power house.

The system of wiring is necessarily very extensive and varied. A large part of the feeder work and basement wiring is open construction with weatherproof wire and porcelain insulation. All concealed work is conduit construction, using high class rubber insulated wire with double protective braid and unlined iron conduits.

Advantage was taken of the opportunity to run loop feeders in some instances, notably in the case of No. 8 feeder, which supplies current for office lighting distributed throughout a building having

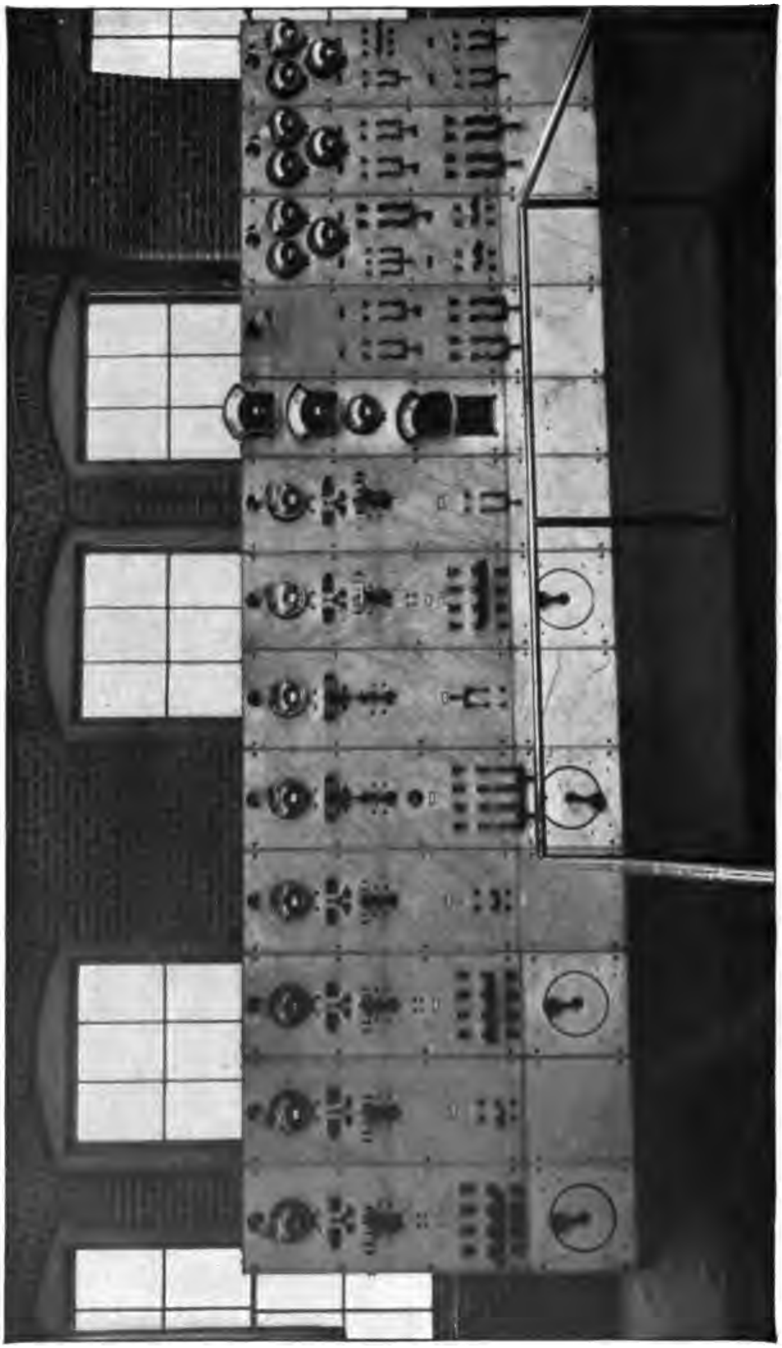


Fig. 182.—Main Switchboard in Power House.

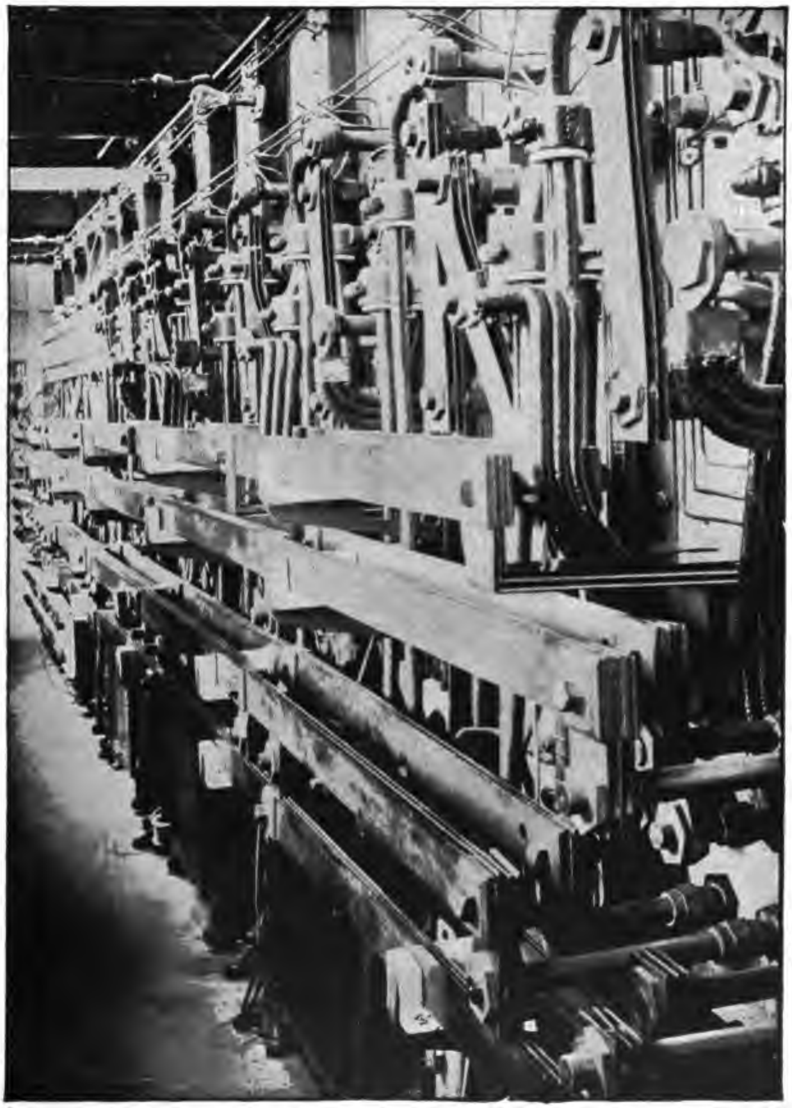


FIG. 183.—REAR VIEW OF MAIN SWITCHBOARD.

FIG. 184.—GLIMPSE OF DISTRIBUTING CENTRE NO. 1, CONTROLLING PUBLIC LIGHTS IN HEAD HOUSE. VIEW SHOWS ONE OF THE ELECTRIC PASSENGER ELEVATORS AT THE RIGHT. (SEE ALSO FIG. 212.)

FIG. 185.—INTERIOR OF HEATING CHAMBER No. 5, SHOWING ELECTRIC TRANSMISSION OF POWER.

a frontage of approximately 2,200 feet. A loop circuit was also used for the attic fan motors and for the elevator motors.

All distributing boards and cut-out boards are of slate, enclosed in slate-lined cabinets and boxes. High grade triple or double pole, double break, jack-knife switches are used, and lugs are extended through boards for back connections. Except in case of the cut-out boxes, all bus bars and wiring connections are on back of boards, and means are provided for making all connections easily accessible. Meter connections are provided in all cabinets and boxes supplying lights to restaurants, barber shop, kitchen, and other premises subject to lease.

The maximum loss of potential between distributing centre and lights was not allowed to exceed 5 per cent. with all lights burning, and no more than 2 volts difference between any two lamps fed from the same centre under any conditions of load.

Cast-iron outlet boxes are installed at all outlets in the concealed work, and provided with substantial fixture supports. Similar boxes are also used for all switch outlets. With few exceptions, the incandescent lamps are 16 candle-power, high efficiency, and arc lamps are of the enclosed type, all lamps operating on a difference of potential of 110 volts. Wherever wiring work is installed in damp places, waterproof construction has been employed.

Railway terminal lighting includes practically every class of service from the occasional basement or attic incandescent to the brilliant waiting-room illumination, including office lighting as well as corridors and service rooms, stairways, restaurants, and baggage rooms, trainmen's house, power houses, signal towers; while the train shed, platforms, midway, carriage concourse, sidewalk, and yards call for an extensive and varied arc-lighting service.

The motors connected number 48 and aggregate 698 horse-power, the largest size being 50 horse-power. They are for the most part 220-volt shunt-wound 4-pole machines of standard pattern. The elevator motors are a noteworthy exception to this, as are likewise the vertical shaft motors for exhaust ventilating fans, and also for the sump pumps, all of which special machines are herein elsewhere described. The motors are as follows:

	Motors.	Horse-power.	Total Horse-power.
For sump pumps	1	10	
	1	30—	40
For elevator machines	6	20	
	15	15	
	3	12—	381
For heating and ventilating fans	2	5	
	2	15	
	1	20	
	1	30	
	5	1	
	1	0½	
	4	4½	
	1	8	
	1	0¾—	122¼
Roll lift drawbridge	3	50	
	1	5—	155
Total	48		698

Heating and Ventilating.

At the outset, two restricting conditions were imposed on the heating and ventilating system. These were, first, that all heat, so far as possible, should be indirect, and, second, that no pipes should be placed above or within 50 feet of either side of the main waiting-room ceiling. Besides these, there were other limiting factors due to certain features of the buildings and the power service, such as great length and small width of the head house and baggage wing; a very large cubic contents (nearly 5,000,000 cubic feet) with a relatively large exposed surface; insufficient and almost inadequate space for suitable size air ducts except for a hot blast system; a nearly complete severing of the building into two nearly equal parts by the main suburban exit with its floor of waterproofing which could not be sufficiently altered to provide passageway for large pipes; and variance in demand for heat and supply of exhaust steam in point of time and quantity.

Designs and estimates were made in connection with Prof. S. Homer Woodbridge for the following four systems, each based on a partial or complete plan of indirect heat:

First. A hot blast system using exhaust supplemented by live steam in stacks, and delivering hot air by blower fans over these to the rooms through the system of air ducts originally provided in the building plans. Removing foul air through vents and

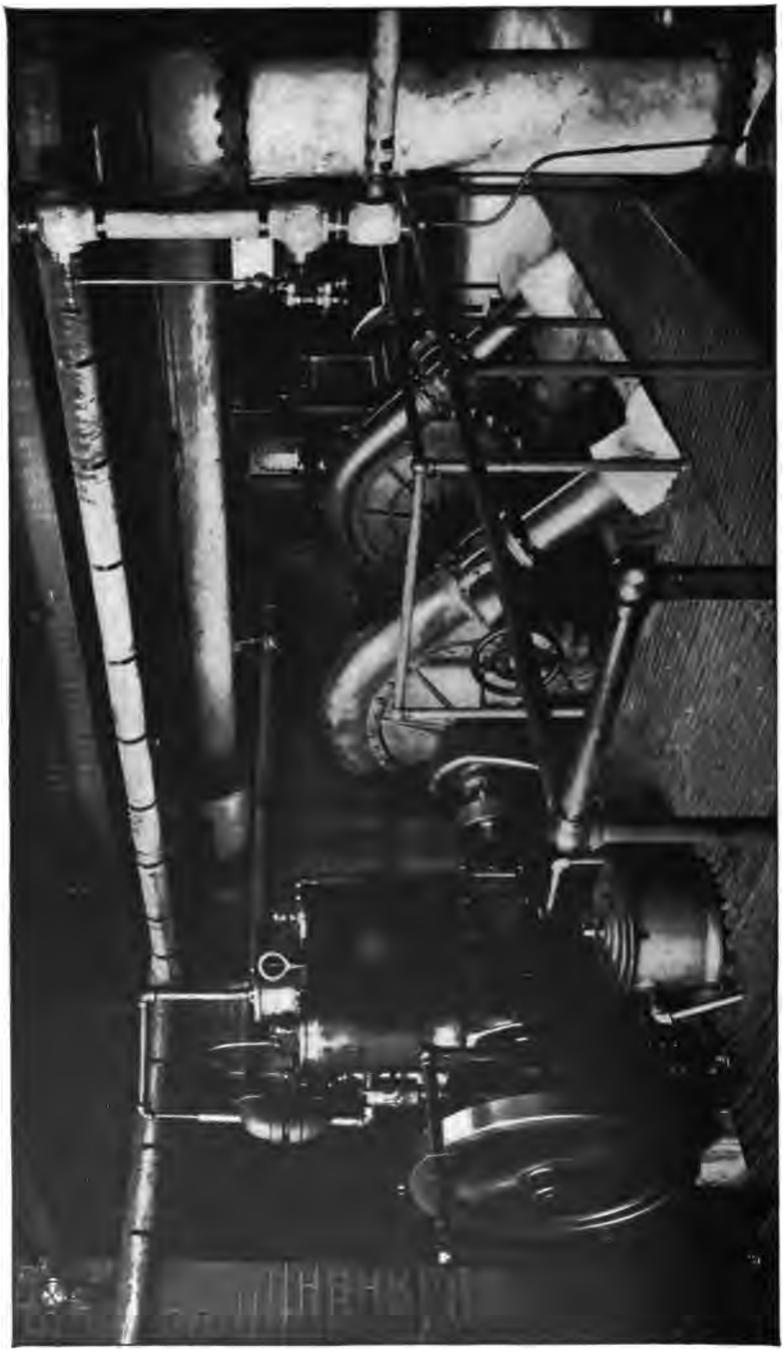


FIG. 186.—HOT WATER CIRCULATING PUMPS, CENTRAL HEATING PLANT. LOCATED IN BASEMENT ROOM, BETWEEN BOILER HOUSE AND ENGINE ROOM.

ducts and discharging above roofs by means of exhaust fans located in attics.

Second. A hot blast and tempered air system supplemented by direct steam radiators in many rooms. In this, the ducts designed for foul air were utilized for tempered air, and the waste spaces around ducts were utilized for exhaust ventilation.

Third. A direct hot water heating system using tempered air for ventilation, doing away with one system of air ducts and utilizing waste spaces around supply ducts for removing foul air.

Fourth. A part indirect hot and tempered air and part direct heat system similar in some respects to No. 2, but using hot water instead of steam.

The first and second were excessive in cost. They required very large and extremely long exhaust steam mains, also difficult and expensive provisions for handling returns. They were also comparatively uneconomical in the use of steam and deficient in certain special sanitary requirements.

Plan No. 3 was the most efficient as well as the least expensive, but involved the use of direct heat to a much greater extent than was permissible, and was abandoned in favor of the fourth system, which best met all requirements.

Hot water was chosen for the circulating medium only after a thorough study of the possibilities and limitations in the use of both steam and hot water. This made it evident that a hot water circulating system in the form of a loop with return mains in transverse subway not only overcame all physical difficulties encountered in the problem of distribution, but, under the rather unusual conditions which surrounded the heating plant, was superior in every respect. The rapid circulation secured by the use of pumps made all points in the system equally accessible and easy to heat. The amount of water necessary to supply the heat required could be conveyed in a flow main no larger than 8 inches in diameter, and without difficulty due to unavoidable pockets at certain points; notably at the main suburban exit.

Owing to the storage value of the large body of water contained in the system, the surplus of waste steam at periods of heavy load could be absorbed, within limits, for use when there might be a deficiency of exhaust at times to reduction of load, and be utilized to a greater extent than possible by other methods. Furthermore, while all heating apparatus must be adequate for the severest weather conditions, the hot water system possessed

FIG. 187.—VIEW SHOWING HOT WATER HEATERS IN CENTRAL HEATING PLANT.

the considerable advantage of being capable of operating at lowered temperatures corresponding to mild or moderate weather, thus preventing waste and discomfort from overheating and undue radiation and leakage losses.

The water is circulated by one of two 8-inch centrifugal pumps, each driven at a speed of about 375 revolutions per minute by an 8½ by 8 Westinghouse Standard engine. The water reaches the pump suctions through the 8-inch return main by way of the transverse subway, and is delivered to the supply side of the system, after becoming heated to a suitable temperature in a central heating plant located near the circulating pumps in the power house. This consists of three specially designed heaters, two being for exhaust, and a third and smaller one for the use of live steam whenever there may be an insufficient supply of exhaust. Two exhaust heaters were used largely because of the inexpediency of installing a single heater of large dimensions, and partly on account of the advantage of having the principal part of the heating plant in duplicate. There was also advantage in regulation, by subdivision. The exhaust-steam heaters are capable of condensing 24,000 pounds, and the live-steam heater approximately 18,000 pounds steam per hour, live steam being admitted to the heater only to supply deficiency, the quantity being regulated by an automatic thermostat valve.

The heated water passes from the central heating plant into the flow main and to the exterior circuit, which forms a loop over five-eighths of a mile in length. This entire system, in which there is necessarily a large amount of expansion and contraction, contains no expansion joints, the design of the piping and the free use of long radius pipe bends permitting the strains due to expansion to be taken up without imposing undue stress on fibre or joint. All turns in the flow and return mains were made by these bends, no elbows being used, thus materially reducing the circulating head, which would otherwise have been excessive except larger and more expensive mains were provided. The engineering problem involved in the proper design, support, and anchoring of these hot water mains was not the least interesting of the several somewhat unusual features of the work. In this connection, it is interesting to note that the actual circulating head proved to be within 2 per cent. of the estimated amount.

Branch connections are made from the mains to five indirect heating chambers, besides many risers and drops connecting with

FIG. 188.—PIPING AND FEEDER WIRING IN DORCHESTER AVENUE BASEMENT. LOWEST PIPE IS 8-INCH FLOW MAIN HOT-WATER HEATING SYSTEM. VIEW SHOWING METHOD OF CARRYING PIPES AND WIRES UNDER STAIRWAY.

Fig. 189.—Interior of Heating Chamber No. 3. This is the Largest of the Five Heating Chambers. The Pair of Large Fans is Driven by a 30 Horse-power Motor, and Supplies Air to a Large Section of the Office Building. The Smaller Fan at Left Furnishes Air to the Main Waiting Room Exclusively.

direct radiators, and the entire piping system is thoroughly covered with non-conducting material. The heating chambers are located at various points in the basements of the head house and baggage wings, and contain the necessary primary heating stacks to temper the air supplied to the building for ventilation. In three of the chambers supplementary heaters are provided for further heating the air required for indirect warming. These chambers are air-tight, and each receives fresh-air supply from above the roofs through vertical intake airshafts. In every case the fresh air is tempered to about 70 degrees, and delivered directly or indirectly by means of suitable blower fans through extensive galvanized iron ducts to the various rooms in the building.

All occupied portions of the buildings are ventilated with a degree of thoroughness seldom found except among such buildings as the best type of modern schoolhouses. This ventilation is constant and is secured quite independently of the means provided for warming; the tempered air contributing little to the required supply of heat. It is worthy of note that a building devoted to railway and office uses, and built on such an extensive scale, should have such excellent and profitable provisions for the health and comfort of public and employees.

The blower fans are driven by electric motors. They supply to the ventilated portions of the building sufficient air to equal their volume every 15 to 20 minutes. A portion of the tempered air supply is diverted from the fan-discharge ducts and is passed through the supplementary heaters, where its temperature is suitably raised for supplying heat to those portions of the building warmed wholly by the indirect method. The hot air is carried in a separate system of ducts, which parallel the tempered air ducts, to points where it is delivered to the various rooms. Specially designed mixing dampers are provided for controlling the proportions of hot and tempered air supply. The use of these mixing dampers is such that the total quantity of air supplied is not altered; their office being to regulate the relative amounts of hot and tempered air, and thus the temperature of the mixture supplied at each inlet. In this way the supply of heat can be increased or diminished without affecting the sufficiency of ventilation.

The form of building, its unusual proportions, and space restrictions made the matter of air distribution rather a difficult one, and necessitated an extraordinary tightness in the air ducts, especially

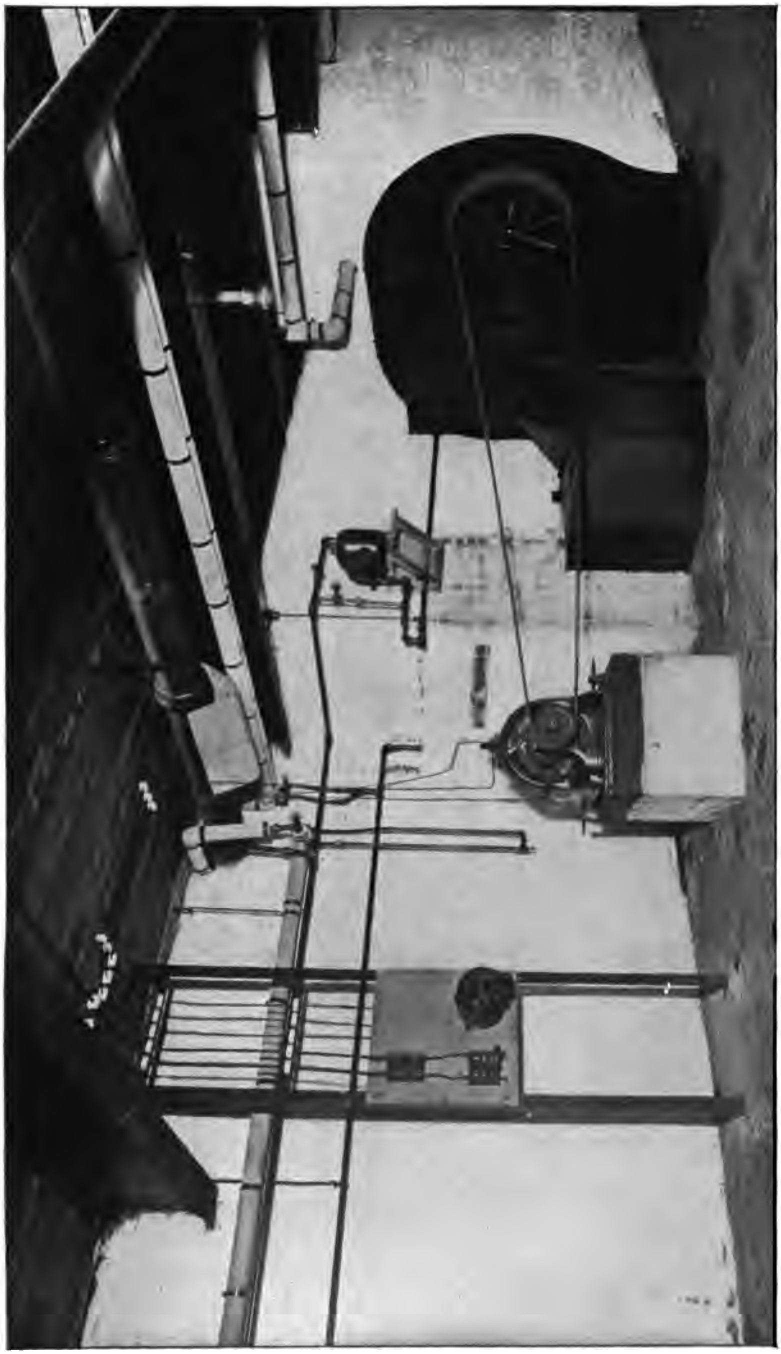


FIG. 190.—HEATING CHAMBER NO. 6. IN THIS CASE THE FAN IS OUTSIDE, AND IS DRIVEN BY A 5 HORSE-POWER MOTOR. TEMPERED AIR ONLY IS SUPPLIED FROM THIS CHAMBER.

as the use of the spaces around the supply ducts for exhaust ventilating flues would have made any considerable leakage a matter of consequence. The unavoidable shape of the ducts, their great length, and the opportunity for excessive heat wastes into the dis-

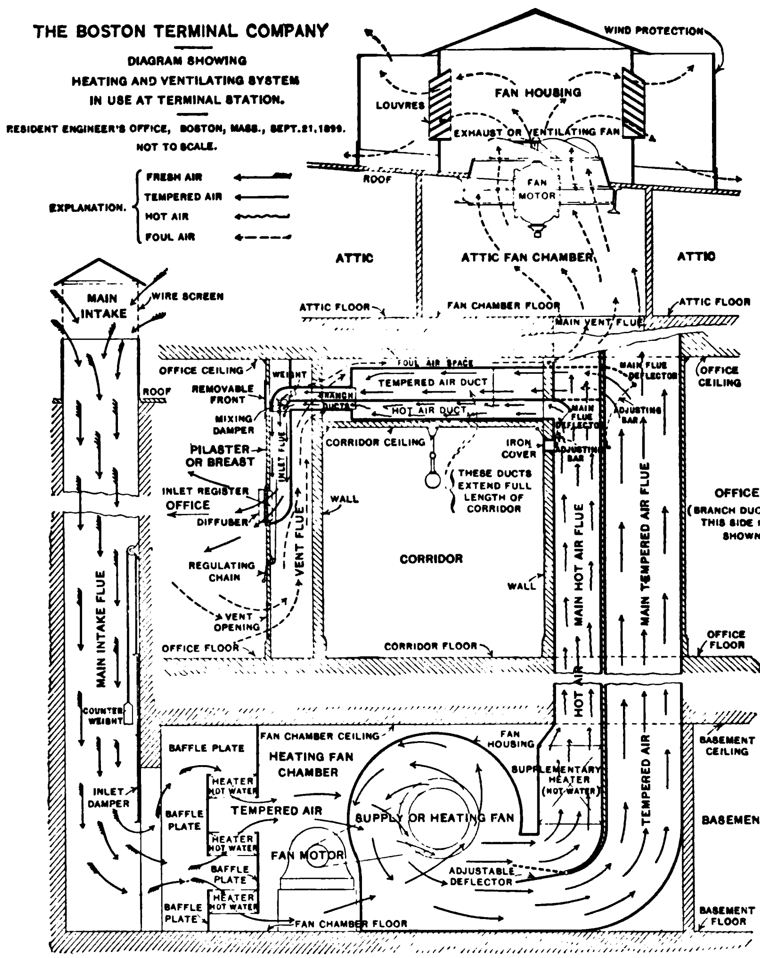


Fig. 191.

charging air, made it necessary to cover the hot air supply system with non-conducting material in order to enable the hot air to reach the more distant outlets at nearly full temperature. Asbestos sea-weed quilt (Cabot's) was used for the work and served its purpose well, although the difficulties in applying any insulating

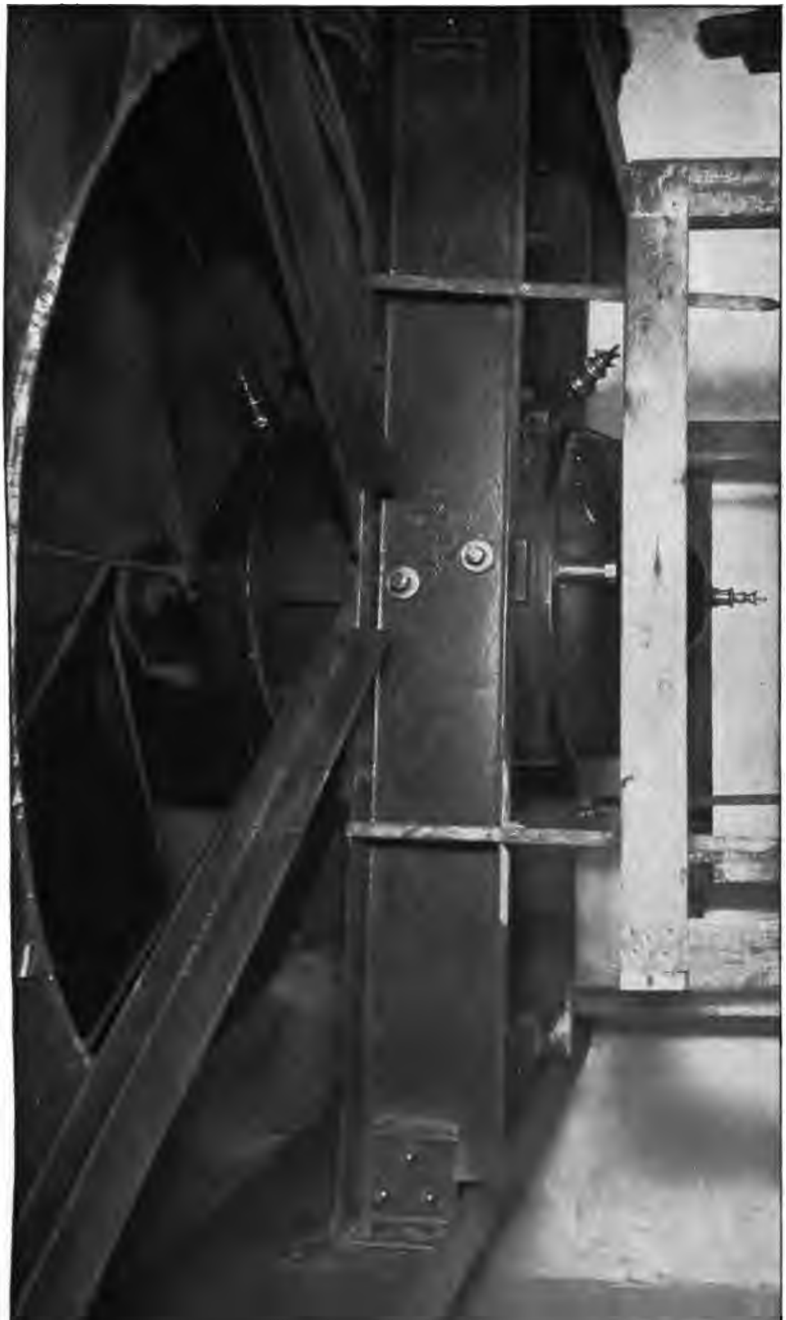


FIG. 192.—72-INCH EXHAUST VENTILATING FAN LOCATED IN ATTIC FAN CHAMBER, SHOWING 8 HORSE-POWER SPECIAL MOTOR AND METHOD OF SUSPENSION FROM ROOF BEAMS.

material were considerable. This arrangement was undoubtedly the best that could be employed under the conditions, although simpler means would have been used had they been permissible.

The ventilation of the building is assisted by 11 electrically driven exhaust fans, which are located in corresponding attic fan chambers, and which withdraw the vitiated air from the building through the waste spaces around the air-supply ducts, discharging it above the roofs. The motors by which these fans are driven are of special design, with vertical shafts, and are dust proof.

The fan wheels are mounted on the upper ends of the shafts, and the motors are in all cases supported by the roof structure. All portions of the air-circulating system are made fireproof.

Direct heat is used in baggage rooms, corridors, and all places where ventilating is not required, and also in certain portions of the building where it was not considered feasible to heat wholly by the indirect method; full ventilation being secured in such instances, however, by tempered air. Direct heat was also used in all lavatories, for sanitary reasons. In all cases these lavatories are adjacent to rooms supplied with fresh air under slight pressures, except in one or two instances, where the entrance is from outside the building, and the air movement is thus always into these rooms from the surrounding spaces. Exhaust ventilation is provided by a separate system of ducts and ventilating fans having no connection with the main ventilating apparatus. The fixtures are vented into air-tight chambers connected with the discharge ducts, the only outlet being through these vents, and a free movement of air is thus assured not only towards such rooms, but into and through each fixture. The contrast between the air in these rooms and in the ordinary railroad lavatory is very marked.

The express building is warmed entirely by direct heat, no ventilation being provided. This building is served separately from a loop of the main heating system, having its origin and return near the central heating plant in the power house. The interlocking towers and yardmaster's building are heated by direct steam supplied from the car-heating system.

Disposal of Drainage from Waterproofed Structure.

The disposal of water from the large area of waterproofed structure required means for pumping, owing to the fact that a

FIG. 193.—PORTION OF 8-INCH HOT-WATER RETURN MAIN TEMPORARILY SUPPORTED IN PERMANENT POSITION IN WHAT WAS AFTERWARD BASEMENT OF EXPRESS BUILDING. PIPE ENTERS WESTERLY END OF TRANSVERSE SUBWAY, WHERE IT TURNS DOWN AND TO THE RIGHT. THE BUILDING WAS HEATED THROUGHOUT THE WINTER OF 1898–99 WITH RETURN MAIN IN THIS CONDITION.

large portion of the basements and all of the suburban loops are some 7 or 8 feet below water level in the bay at high tide.

In considering the drainage of this large area, it was necessary to take into account the possible seepage, the probable quantity of storm water, and to provide sufficient pump capacity to handle both at time of flood tide. There was no way to predetermine the seepage, although a pumping capacity of 1,000 gallons per minute was considered more than ample to handle any probable amount of water which might find its way to the pump from this cause.

The question of storm water was capable of more exact treatment, as in the latitude of Boston the rainfall seldom exceeds 3 inches per hour, and never for long enough periods to cause more pumping than such fall would require. The area exposed to storm water is approximately 91,240 square feet, and upon this surface it was estimated that 171,759 United States gallons of water might fall per hour at a 3-inch rate. It was assumed that about 25 per cent. more water would be driven from tops of retaining walls, surrounding embankments, yards, etc., making a total of 214,698 gallons as the total maximum quantity of storm water to be pumped per hour. This gave 3,578 gallons per minute, and an 8-inch centrifugal pump was chosen, capable of discharging 4,000 gallons per minute under the conditions of head and speed imposed.

It was not considered that snow and rain could swell the total to an uncontrollable amount, for the presence of snow and ice would retard the flow sufficiently to check the speed with which the water from a heavy downpour would reach the pump, and in general it was concluded that the natural resistances to water-flow would prevent accumulation at the well faster than could be handled by a 4,000-gallon pump.

The use of two pumps was regarded as essential for service as important as this, in order that one might relay the other. A single pump, if disabled, would be flooded, and could not be reached for repairs. By dividing the pump capacity unequally, and arranging the smaller pump to deliver its full capacity of 1,000 gallons per minute against a 16-foot head (the most extreme condition), and the large one to deliver its full rated capacity of 4,000 gallons per minute against a head of 13 feet 6 inches, and a correspondingly smaller quantity against heads up to the maximum of 16 feet, the larger pump was enabled to work to its fullest

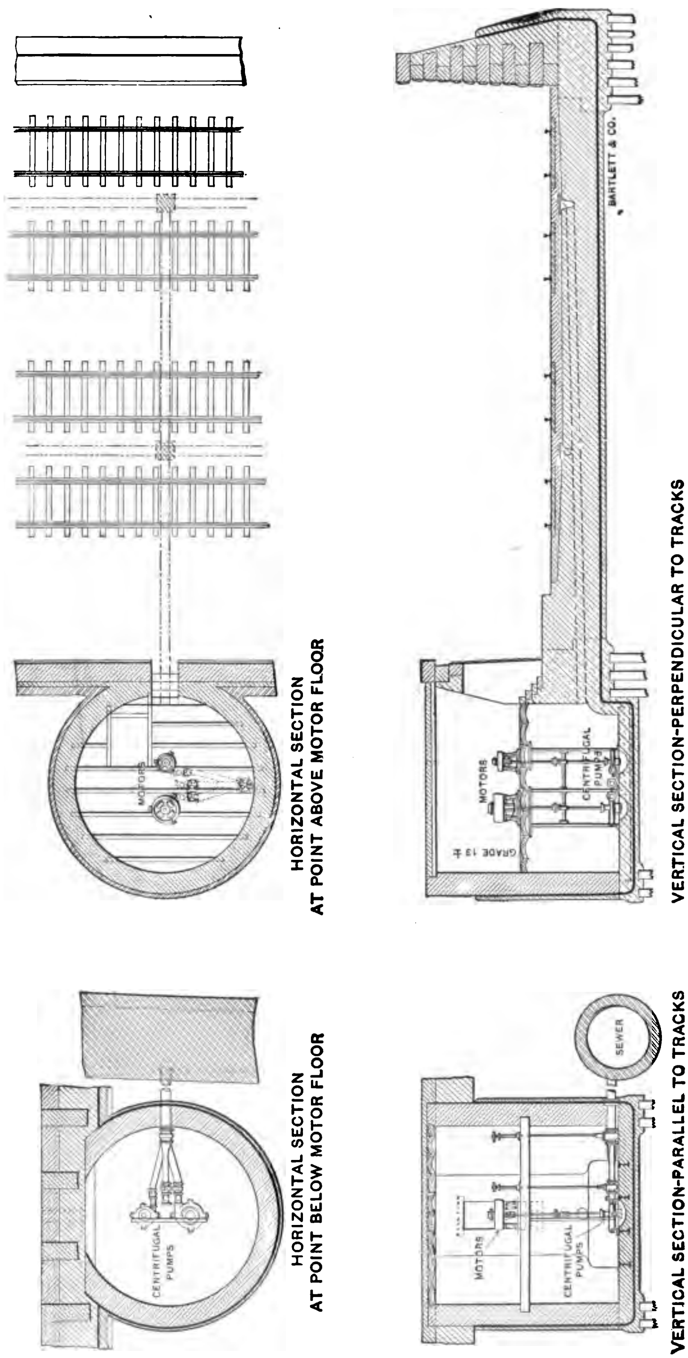


FIG. 194.—GENERAL ARRANGEMENT OF SUMP.

capacity and best efficiency against amounts of water that would accumulate in the sump more than 2 feet 6 inches deep. The smaller, or seepage pump, works to its full capacity against the entire 16 feet required at times of extreme high tide; thus giving this pump as long a period of operation as possible, and avoiding the undesirability of too frequent stops and starts. Seepage waste and ordinary storm water is therefore handled by a very moderate size light running pump, which does nearly all of the work required, while the storm pump is preserved for emergency work and relay. Both pumps are electrically driven, and each has a special vertical Westinghouse motor coupled directly to the upper end of its shaft. The pumps are submerged, and discharge through suitable check and gate valves into an adjacent sewer. When the accumulation of water is sufficiently small, the check valves act as tide gates, and allow the water to discharge to the sea at low water without the aid of the pump. Provision is made in the design and arrangement of piping, valves, and connections, for the installation of a third pump should its use at any time be required. Considerations of corrosion, electrolytic action, and life of materials led to the choice of cast-iron cases and bronze running parts and bolts for all submerged work. The shafts and bolts are of Tobin bronze. The weight of motor armatures and other moving parts is carried on suitable thrust bearings located between the pumps and motors, and supported on structural work provided in the sump for the purpose.

The small pump is arranged to start and stop automatically by the rise and fall of the water in the sump, through the use of suitable controlling devices actuated by floats. The ordinary work of pumping therefore takes care of itself, and little or no attention to the operation of the machinery in the sump is required. A high-water indicator is also provided, and connected with a loud ringing gong in the power house, to give alarm in case the water should accumulate above the higher limit handled by the small pump; the arrangement being such that the bell will ring constantly and alarm the power-house crew if the water stands at or above a predetermined danger level. The large pump is started and stopped by throwing a jaw switch by hand in the usual way.

The walls of the sump well are built of brick, and the roof and floors of iron and masonry. The motors and controlling devices are located on the upper of the two decks, and the pumps at the bottom of the well, the lower chamber being reached

FIG. 195.—INTERIOR OF UPPER CHAMBER IN SUMP. THIS WELL IS TWENTY FEET IN DIAMETER, AND PUMPS ARE LOCATED IN CHAMBER BELOW THE ONE SHOWN. VIEW SHOWS SPECIAL MOTORS WITH VERTICAL SHAFTS, AND SWITCHBOARD WITH CONTROLLING APPARATUS.

through a trap-door by means of iron stairs and platforms. The well is lighted by electricity, and the upper chamber warmed by steam to prevent excessive deposition of moisture from the atmosphere on the otherwise cold surfaces.

The sump is located near the power house, with entrance in the side of the easterly retaining wall of the depression for the suburban loop tracks; and all portions of the waterproofed area, which aggregate several acres, are connected with the well by half-section tile drains, imbedded in the concrete under the stone ballast.

The operation of the sump has been exactly as contemplated, and satisfactory in every respect, the only emergency so far met being a considerable and unexpected quantity of water driven, during a heavy storm at an extreme high tide, over the top of some sheet piling used in connection with construction work.

Roof Drainage.

One of the more unusual problems met in the work was in connection with the drainage facilities for the large train shed and head house roof areas, aggregating about twelve and a half acres. The climate of Boston is particularly unfavorable to roof drainage on such a large scale, the variable temperature causing alternate thawing and freezing, thus conducing to blocking gutters and bursting leaders. The arrangement of valleys and adjacent windows was such that it became absolutely necessary to carry away water at all times and under all conditions and also to prevent the undue accumulation of snow and sleet in the principal valleys.

There were some two dozen copper or cast-iron leaders varying in size from 6 inches to 12 inches in diameter, and some were over 600 feet long. All were to be exposed to severest freezing weather—most of them throughout their entire length—and in many cases there were of necessity long horizontal runs. Nowhere could any method be found in use where such conditions were being met with even partial success; the difficulties at the Northern Union Station in Boston, the most analogous case, being particularly troublesome.

A consideration of all the conditions to which such drainage is subject led to the conclusion that it was useless to attempt any extensive thawing of snow or ice on the roofs, and that whatever expense might be incurred should be concentrated principally upon the leaders to keep them clear at all times, in order that whatever water might result from rain or melting snow would not accumu-

FIG. 196.—MAIN CROSS-OVER IN APPROACHES TO SUBURBAN LOOP. POWER HOUSE TO RIGHT OF VIEW, AND PIPE BRIDGE FORMING PART OF TRANSVERSE SUBWAY AT LEFT. DOOR IN RETAINING WALL, NEAR BARRELS, IS ENTRANCE TO SUMP. THE OBJECT AT UPPER RIGHT-HAND CORNER OF VIEW IS POWER-HOUSE STACK, NOT A WATER TANK.

late in the valleys, but always find channels of escape. Nothing further than this, except means for keeping an open channel in one of the principal gutters, has been found necessary, and during the severe winter of 1898–99 the means provided were found adequate.

Of the several methods devised, a most practical one proved to be the one finally employed. It consisted in jacketing each of the principal leaders with heavy wire lathing and an inch of asbestos sponge, with an air space of about one and a half inches between the jacketing and the leader pipes. This jacketing was constructed in a very substantial manner, supported every two feet on heavy wrought-iron clamps, and all covered with heavy canvas sewed on tightly and thoroughly painted. The jacket space on each leader is kept warm in the most extreme weather by a single run of 1-inch steam pipe with its return, the entire system being conveniently connected with the car-heating mains.

Provisions were made in some instances by the use of suitable U traps in the basements to seal the lower ends of the leaders against undue air circulation.

As compared with the usual method of melting snow, the use of steam for keeping the jackets warm and the leaders above freezing point is small. The warmest spots in the roof are at the mouth of each leader, and these are consequently comparatively open, thus facilitating drainage toward the outlets. In only one instance, namely, the valley between the midway roof and the head house, has it been found necessary to make additional provisions for handling snow and slush; but in this case the valley is so large and shallow that it has been found necessary to facilitate the flow of water to the down spouts, and a single run of 2-inch brass pipe has been provided for the purpose. This may be used to a limited extent for melting snow if desired; but is intended primarily to keep the gutter open, and thereby greatly increase the opportunities for melting snow to filter through the slush and flow to the outlet points.

The use of steam, in addition to the protection afforded by the jackets, is seldom required; but during the few days when used last winter the results were good.

Ice-making, Refrigerating, and Water-cooling Plants.

A problem requiring careful study was how best to meet the needs of the new station for an efficient and economical service

FIG. 197.—INTERIOR OF TRAIN SHED, SHOWING SEVERAL OF THE COMPLETED ROOF LEADERS AT SIDES OF TRAIN-SHED COLUMNS.

for all purposes requiring cooling work. These included the cooling of drinking water for passenger cars of all descriptions, as well as chilling the refrigerators of dining cars; the filtering and cooling of drinking water for public waiting rooms and corridors and for offices and restaurants throughout the buildings, and the chilling of cold storage rooms and kitchen boxes used for restaurant and florists' business. Unlike the several other operating departments of a large railway terminal which are, of necessity, items of direct expense, ice-making and refrigerating service offered opportunity for substantial earning power. While similar cooling is often done wholly by the melting of ice purchased or made for the work, it was recognized that much of the expense, dirt, and annoyance incident to the old method could be obviated by the use of mechanical refrigerating processes.

The superiority of mechanical refrigeration over the use of ice for restaurant refrigeration was very evident. Its use would secure lower temperatures in storage boxes; a greater percentage of space available for storing goods; dry air in boxes with the resultant ability to store goods indefinitely, instead of a wet atmosphere and slimy boxes; reliable and uniform cooling instead of temperatures varying as the ice melted away; less operating cost for the service by using a much cheaper cooling medium, and by saving all labor in ice handling; and increased rental value of restaurants. In the general investigations that were made of other railway terminals, it was ascertained that the use of artificial ice and mechanical refrigeration is very common in the more important stations, except in the northwest, and is much preferred on any basis of price. Except in Chicago, it was found cheaper to manufacture than buy the natural ice. Restaurant refrigeration, where done with ice, either manufactured or natural, was invariably condemned as inconvenient because of foul, wet boxes. The data which were secured revealed, among other things, the facts (1) that the three railroads using the new terminal consume less ice per train per day, or make more runs on one icing, than at other large terminals, due to large suburban traffic and lower summer temperatures; (2) that smaller weights of ice are used per car, but more cars are iced per train handled.

The probable ultimate ice and refrigerating load for the terminal was ascertained after a close study of the needs and methods of other large railroad stations. The maximum monthly and total yearly requirements for all purposes were determined, and a close

relation established for the maximum, minimum, and mean ice consumption throughout the year. From a yearly load curve plotted from this data, the requisite ice storage to equalize the excessive consumption of the four summer months was fixed at 800 tons, this storage space being provided under the ice-freezing tank.

A nominal daily capacity of 20 tons of plate ice was selected as best meeting the conditions, which, with the ice storage provided, makes 26.5 tons of ice available daily for four hot-weather months, in addition to the refrigerating and water-cooling loads. These other gross loads were similarly found, and the sum of all determined for maximum load conditions.

For the commercial manufacture of this artificial ice there were two general methods available, commonly known as the "can" and the "plate" systems.

In making ice by the can system, galvanized iron cans containing the water to be frozen are immersed in a brine bath maintained at a low temperature by submerged cold ammonia expansion coils. The water is frozen *inwardly*, and any air or impurities existing in the water are, of necessity, frozen into the centre, or core, of the ice block. To so make clear ice, it is therefore essential to use distilled water, carefully filtered and purified.

In the plate ice-making process, the plant is simplified by submerging the cooling, or freezing coils directly in the fresh water to be frozen and allowing the ice to form on the outside of these coils, from which it is then cut. The water is frozen *outwardly*, excluding the air and impurities into the residual unfrozen water.

The complex, intersecting crystalline structure of can ice (frozen from all sides) and its softer core, result in a so-called "rotting" of the cakes unless stored in a temperature below 32 degrees, and makes storage unsatisfactory. The cost of distilling and purifying the water is also large as compared with the plate system.

The direct ammonia expansion plate system is much simpler; has fewer purifying and freezing processes, and the character of the ice product is denser, clearer, without core or other impurities, and has much better storing qualities than ice frozen in cans, and was considered superior in every way. For all these and other reasons the plate system was preferred, and a plant using the anhydrous ammonia compression system, as built by Westinghouse, Church, Kerr & Co., was installed.

The ice-making plant being the largest, and in some respects the leading, feature of the mechanical cooling system, had a determin-

ing influence on the design of the balance of the refrigerating work. All water cooling and all the refrigerating work, except the chilling of the ice-storage cellar, was to be done in the head-house building, at distances varying from 1,000 to 2,000 feet from the power house building. To properly transmit these long distances without undue losses was an important consideration in the design of the plant. Both the direct ammonia expansion and brine circulating systems were available for this work, with some advantages in favor of both. First cost, conditions of operation, character of the service, and temperatures to be held, were the leading factors in the selection for this service. Direct expansion cooling was the cheapest, and would give lower temperatures and greater refrigerating capacity with the same compressor displacement than the brine system; but very low temperatures were not required, and the slight saving in power and first cost were more than overbalanced by substantial advantages in operation and control, secured by the general use of brine circulation under the set of conditions met at the station. These considerations did not apply to the water-cooling service, however, and direct expansion was accordingly employed for that work.

The three principal divisions of the terminal cooling plant—namely, the ice making, refrigerating, and water cooling—are but separate parts of one general system, taking power from the common high-pressure steam supply of the power plant. They are, of necessity, closely related and are grouped together, although independently operated outside of the engine room of the ice and refrigerating building.

The size and design of the ice and refrigerating room, and the general arrangement of machinery, are shown in the accompanying illustration. The plant is located on north end of power-house building adjoining the engine room, but isolated therefrom by a brick partition, built as high as passageway for the overhead engine room crane would permit. This crane is arranged to handle any part of either ammonia compressor as well as the machinery in the engine room.

A photograph taken from floor level and from upper left-hand corner of plan view of this room shows the two ammonia compressors. Both cuts show the ammonia condenser and ice-making tank. These were placed in upper portion of building to permit of storing 800 tons of ice in the insulated cellar space, there being no other room available for the purpose. This ice storage helps

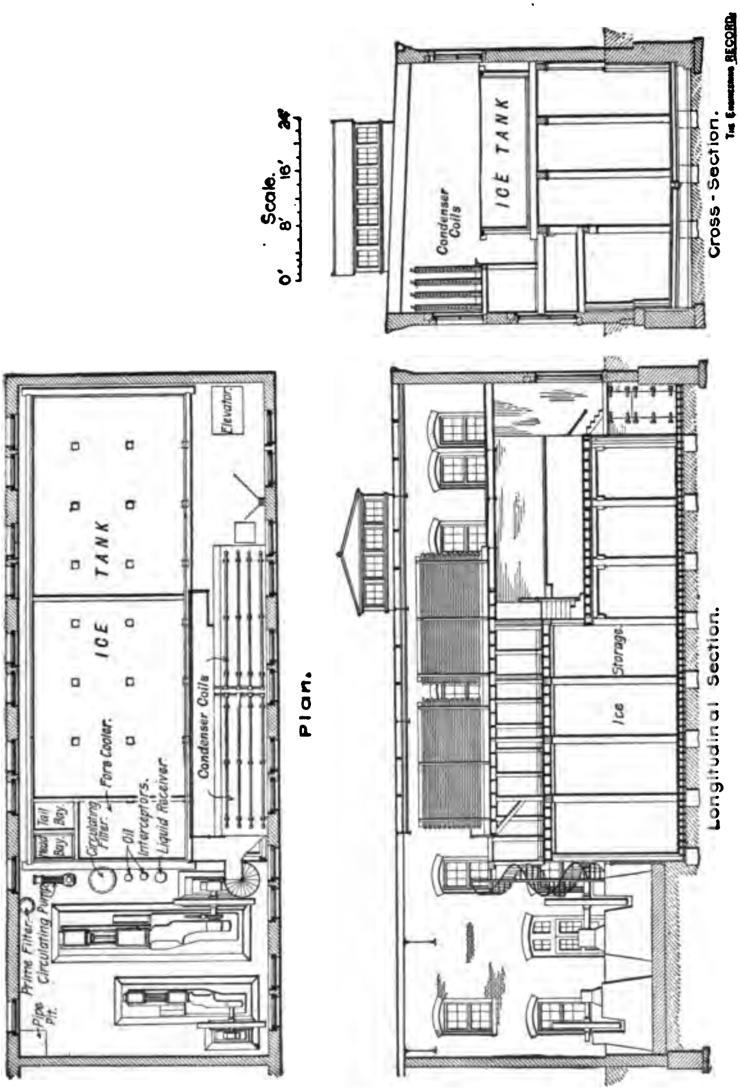


FIG. 198.—GENERAL ARRANGEMENT OF ICE PLANT.

to care for the excessive summer ice consumption; permits of uniform running conditions and smaller compressor capacity, and, in conjunction with the small compressor, provides ample relay machinery to insure continuous service. By placing this apparatus close to the power plant, a saving in operating labor is effected, and refrigerating transmission losses are avoided by using direct ammonia expansion cooling for the brine and water of the remote refrigerating and water-cooling plants in the head-house building.

Two ammonia compressors were installed, the larger being of sufficient capacity to handle the entire maximum load, while the smaller was made 50 per cent. larger than the combined maximum box refrigerating and water-cooling loads. Cylinder sizes are:

Steam,	**20 inches by 32 inches, and 14 inches by 20 inches**	double acting;
Ammonia,	**16 " " 32 " " 10½ " " 20 "**	

respectively for the large and small compressors. These compressors may be run with steam cylinders condensing or non-condensing. The compressors are especially designed for the handling of gas, either dry or carrying a large excess of liquid ammonia; *i.e.*, for either "dry" or "wet" compression, without any change in adjustment.

Horizontal compressors were used to secure ease of operation and safety by free discharge of liquid ammonia under the varying conditions to be met. Besides being strong and stiff under high pressures, this tandem Corliss machine shows less friction than other types, and the highest steam and mechanical efficiencies are therefore secured with the other advantages obtained. The ammonia cylinders have completely removable water jackets on sides, heads, and stuffing-box. Constant low temperatures of all working parts and increased gas displacement are thus secured. These compressors run on very nearly as small a clearance as is customary with single-acting machines, and secure another advantage commonly found only in the latter; namely, the packing of ammonia piston rods against low pressure only, by using a double-packed stuffing-box with oil chamber around rod between packings, which chamber is fed with oil under a slight head, and is also vented by a pipe connection to the suction or low-pressure side of system. This feature is not, however, peculiar to this machine, being used in a different form by some other builders. The results are excellent, as leakage of ammonia, hard packing, and cut rods are effectually avoided.

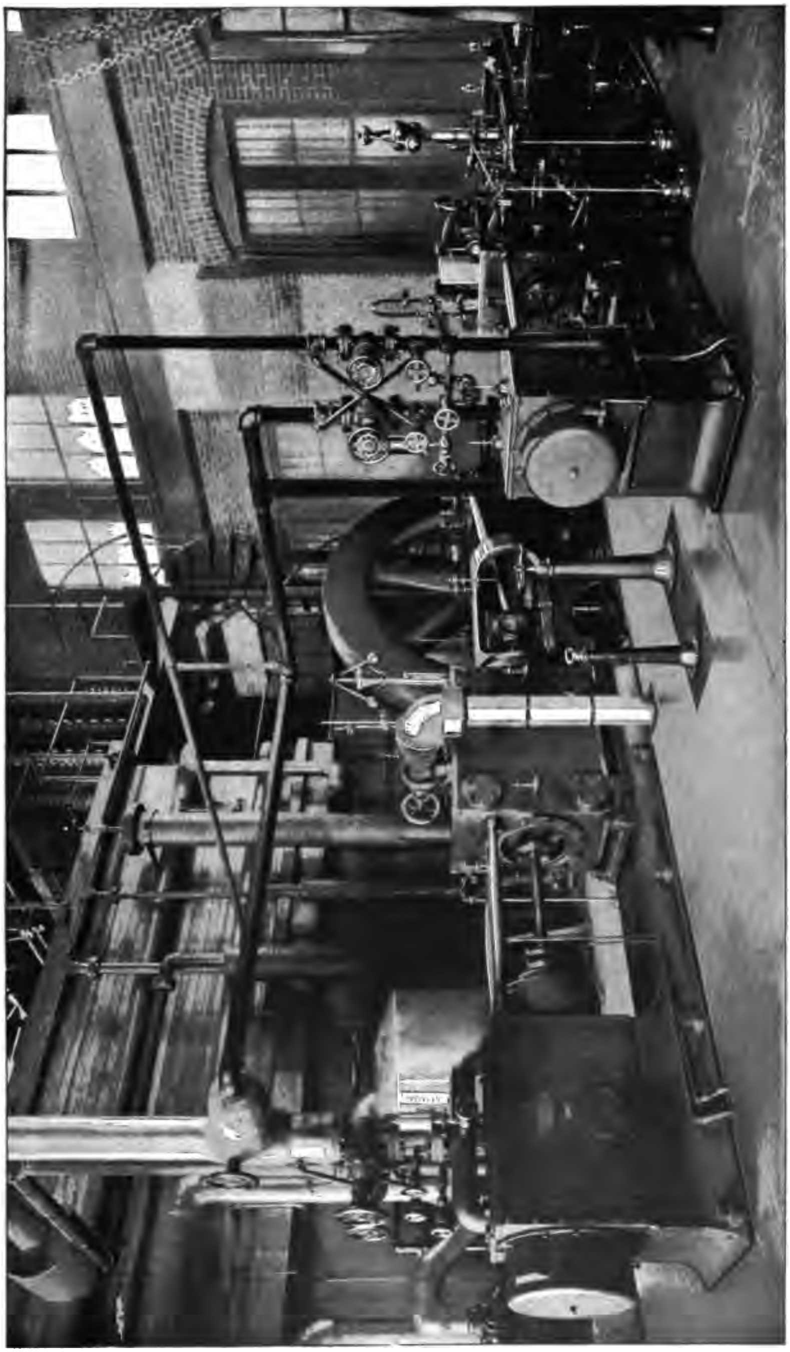


FIG. 199.—AMMONIA COMPRESSOR ROOM. ICE PLANT FREEZING TANK IN UPPER LEFT-HAND CORNER OF VIEW. AMMONIA CONDENSER IN BACKGROUND.

The ammonia condenser and top of freezing tank are shown in illustration. This condenser is of the sectional atmospheric style, of 2-inch extra heavy pipes 20 feet long and made up with extra heavy steel return bends, each connected by gas inlets and liquid-drain headers to its companion coils. Eight sections are used, each 24 pipes high. All pipes and fittings are heavily "Kalamined" to best resist the corrosive action of the salt water used for condensing purposes. This condensing water is fed to the coils from a heavy brass serrated trough placed over each coil section. Each coil may be isolated by closing its valves, and is provided with separate vents to atmosphere and to suction pipe to evacuate contents when desired. The Baudelot type of ammonia condenser, with initial hot gas cooling coil, placed under main condensing coil to extract the superheat from the gas entering condenser, was not used in this case, as the slight percentage gained figured so small that, with salt condensing water costing nothing except its pumping, simplicity and few condenser joints were deemed of greater value.

The freezing tank is made of heavy yellow pine framing, with 3-inch cypress lining, and is designed to make 20 tons of plate ice daily, from undistilled city water passed through an initial filter before charging into freezing tank. No brine is used. The freezing tank contains 6 feet depth of filtered fresh water, in which continuously welded, vertical coils of horizontal pipes are submerged. The freezing is accomplished by expanding liquid ammonia within these coils, causing the ice to form on the outside of coils. The ice, thickening as it freezes, extends sideways toward the plates of ice forming on adjacent coils. The coils are placed about 30 inches apart on centres, and the ice is cut therefrom when about 12 inches thick on each side of the coil. The ice on adjacent coils is not permitted to freeze together, and hence all the impurities expelled by the ice remain in the residual water, which is continuously circulated by a pump, between each pair of coils, entering at one side and overflowing on the opposite side of the freezing tank. This water is then drawn through a large deaërating quartz filter before being returned to the freezing tank, and the rejected, insoluble matter is thereby trapped and eliminated. Fresh water to replace the volume of ice withdrawn is automatically charged from city main into the forecooler tank, whence it is automatically fed by ball cock, into a tail bay, located in the suction run between freezing tank and circulating

FIG. 200.—TOP OF FREEZING TANK, SHOWING AMMONIA CONDENSER.

pump. The circulating pump discharges into the head bay compartment, from which the water flows by gravity through a pipe header along the front of freezing tank, and is discharged between each pair of coils, to be again similarly circulated. The incoming warm fresh water in forecooler is chilled by a pipe coil of generous area inserted in the ammonia-suction line to compressors, using the excess of liquid ammonia passing through the freezing coils for this initial cooling work. The harvesting of the ice from the freezing coils is done by steam cutters on the " block " system. These cutters consist of a frame mounted on wheels to run over tank covers, with a framework supporting vertical guides, and carrying a rectangular vertical knife frame of depth sufficient to reach to bottom of freezing tank. This knife blade has a small copper steam pipe secured to the lower edge. Flexible, insulated steam and drip connections are made to this moving knife edge from an overhead piping system swinging radially on a track from the middle line of tank. The hot knife edge melts a kerf in the ice by its own weight, the cutter blade following in the slot to the bottom of the tank. Both sides of a channel are cut simultaneously, the cutter's blade hoisted by a chain and hand crank, and the frame then shifted forward for another cut. Two cuts of this cutter are made per ton of ice harvested. The ice cakes are quickly hoisted from the tank by a pneumatic hoist on an overhead track, weighed in the air, and run on track to the elevator in north end of building, and lowered to the ice storage cellar or to the shipping room. Ice is cut up as desired in the shipping room, and supplied by a gravity incline to small push carts, in which it is distributed to the cars in train shed, to the restaurant, and to a few water-coolers. Shrinkage of ice in the storage cellar is avoided by overhead direct ammonia expansion refrigerating coils. Accompanying cut shows the method of harvesting by a hand hoist in an ordinary " block " ice plant.

The exceptional purity of the ice obtained at the terminal by this freezing process warrants some mention. In three respects was this noted, viz.:

(1) The almost complete exclusion of bacteria by freezing; the average reduction being over 99 per cent. with the temporarily impure water used in the first six weeks' freezing.

(2) The small number of bacteria found in the tank water after cleansing and refilling tank and using same for four weeks; thus evidencing the fact that the low temperatures prevailing dis-

FIG. 201.—HARVESTING PLATE ICE IN A TYPICAL BLOCK ICE MAKING PLANT.

couraged bacterial growth. Analysis showed 1,790 bacteria per cubic centimeter of this tank water when the city water supplied to tank contained over 20,000 bacteria per cubic centimeter. The plate ice frozen from the same water averaged about 100 bacteria per cubic centimeter.

(3) The great reduction in the amount of other suspended and dissolved matter. The total residue obtained by evaporating to dryness showed that under the worst conditions the ice contained only $\frac{1}{17}$ as much matter as the tank water from which it was made, and that even with the impure tank water used in the first six weeks' freezing, the resulting ice contained only $\frac{1}{8}$ of the impurities found in normal Boston drinking water taken from mains on the same date. In general, the ice was found to be almost as pure as commercially distilled water, and quite as pure as an average sample of can ice made from distilled water. Such impurities as are found in the plate ice are inert and inoffensive, while the can ice core is frequently highly offensive, on account of the presence of lubricating oil from the exhaust steam used, mixed with zinc and iron carbonates dissolved from pipes and tanks.

All the ammonia piping throughout the plant was made of extra heavy pipe with extra heavy steel fittings. Oil traps, ammonia liquid receiver, pipe covering, pressure and recording gauges, ice harvesting and other tools, equipment and accessories are of the usual styles furnished for such work.

The liquid anhydrous ammonia is piped direct to the far centres of distribution in the head house, expanded and evaporated to dry superheated gas in submerged coils in a refrigerating brine tank and similar fresh-water cooling tanks, and is returned at normal temperature, in an uncovered suction pipe, to the compressors. Insulation on a suction line of this length would not save enough to pay for its interest and repairs, for the losses are limited to an increased compressor displacement sufficient to cover the increased volume of the returning dry gas in expanding from zero to 70 degrees. Where liquid ammonia or supersaturated gas is drawn through the suction lines, as in the ice plant, it is of course essential to cover them.

The brine circulating system is used almost exclusively for cold-storage work. A large rectangular steel tank, thoroughly insulated, was placed in the cellar and filled with a strong salt brine solution. This brine is cooled with a number of submerged ammonia coils, handled by either ammonia compressor, and is then circulated by

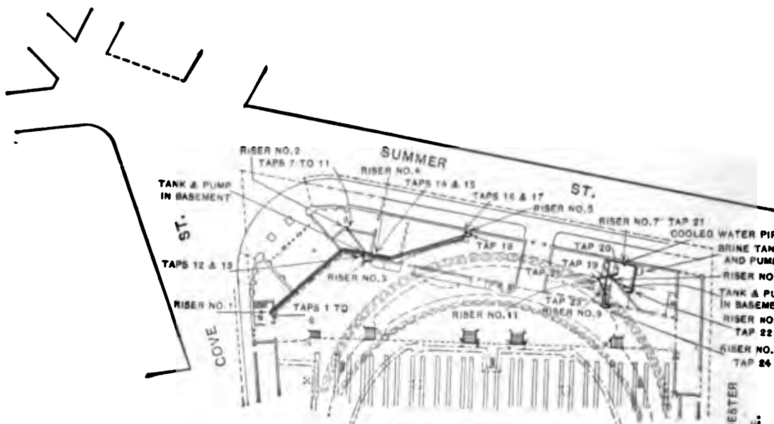
FIG. 202.—TOP OF ICE TANK—HARVESTING ICE.

FIG. 203.—INTERIOR VIEW OF ICE STORAGE ROOM UNDER FREEZING TANK. STORAGE CAPACITY, 800 TONS.

FIG. 204.—VIEW IN SUMMER STREET BASEMENT OF HEAD HOUSE, SHOWING ONE OF THE WATER-COOLING TANKS AND CIRCULATING PUMP AT LEFT, BRINE TANK AND CIRCULATING PUMP FOR REFRIGERATION IN CENTRE, AND ONE OF THE THREE HOT WATER STORAGE HEATERS WITH THERMOSTAT VALVE AT RIGHT. FILTER FOR WATER-COOLING SYSTEM IS BEYOND END OF BRINE TANK AND CANNOT BE SEEN.

a steam pump through well insulated pipe lines to and through galvanized cooling pipe coils in each refrigerator and back to the tank. The brine is carried at about 10 degrees Fahr., and box temperatures of 20 degrees and upwards are obtained at will by regulating a supply valve on each box coil. For small work of this character, better results in the way of constant temperatures and easy regulation are obtained by brine circulation than by direct expansion in the boxes. The cold rooms and boxes are located on the basement, first floor, and second floor levels.

The water-cooling plant is similar to that provided for refrigerating work in many respects. It was desired to supply with cold drinking water at least 25 taps scattered throughout the building. This was accomplished by using two cypress water tanks, one at



PLAN SHOWING DISTRIBUTION OF WATER COOLING SERVICE.

FIG. 205.

each centre of distribution, supplied automatically with filtered city water, which was cooled by submerged galvanized welded ammonia coils connected with the mains leading from the power-house compressors.

A pump at each tank circulates the chilled water through a number of loop pipe circuits and back to the tank. Dead ends at the taps are avoided, thus enabling cold water to be drawn promptly without waste. A constant back pressure is maintained on all taps by a regulating valve, and the rate of flow is from all taps the same regardless of level. This uniformity is secured by use of a special diaphragm fitting with a hole of the proper size to

pass the desired amount of water under the pressure existing at tap. The proper size of these holes was determined by a series of tests under different pressures.

The advantages of this method of cooling drinking water are much the same as cited for refrigerating work. The storage tanks act as flywheels to equalize the loads, and a constant temperature of about 40 degrees is furnished at the taps, this being regarded as the most desirable temperature. This service is a great improvement on water-coolers.

Car Heating in Train Shed and Yards.

This system is designed to simultaneously heat 150 cars in extreme cold weather, thereby keeping trains ready for passengers independent of steam from locomotives. All this work is done by live steam from boilers. Suitable pressure reducing valves are placed at the far ends of the steam supply lines before they branch for distribution to the stub tracks in yards and train shed. This permits the use of small steam supply lines to the centres of distribution, by allowing portion of the pressure to be reduced by friction in the mains. Two pressure reducing valves are used, placed one in head house under the carriage concourse, and one in the transverse subway. These valves deliver a pressure at cars varying from 50 to 70 pounds, according to the season's requirements. The use of hose is avoided entirely; the car connection being quickly coupled to the wrought-iron pipe line by the usual train coupling. The necessary flexibility is secured by a new form of self-packing universal coupling. The lines are dripped by steam traps, and precautions have been taken to avoid trouble from expansion or from freezing. One steam and one compressed-air connection are provided at the end of each stub track. In all respects the system is in accordance with the best practice of other leading terminals, but embodies some improvements.

Air-brake Charging.

This system of piping was designed to serve the ends of 28 stub tracks in the train shed, and a number of additional tracks and sidings in the yards. The outlets are located near the steam outlets of the car-heating system. By means of a generous supply of air, stored in a number of large steel tanks connected with

the compressed-air piping system, the air-brake car reservoirs are quickly charged before the locomotive is attached, and provision is made for testing the application and release of the brakes with a special 3-way cock if required, although it is intended that this testing should ordinarily be done from the locomotive as usual. The compressed air for this work is supplied by an independent plant, having no connection with the air supply for switch and signal work. This plant consists of two standard 9½-inch Westinghouse locomotive air-brake pumps mounted on the wall of the engine room in the ice and refrigerating building, and equipped with automatic governors for controlling the air pressure in the system. One governor is regulated to open at a lower pressure than the other, and starts up its pump when the draught is heavy enough to reduce the pressure below the point at which the regulator of the other pump is set. An air pressure of from 70 to 80 pounds is commonly carried. The air reservoirs and low points of pipe lines are dripped to prevent accumulation of moisture and consequent trouble from freezing. The 3-way cocks at outlets in train shed are each furnished with 10 feet of air-brake hose, with coupling for quickly attaching to the train pipe system, and at the outlets in yards metallic connections similar to those used for steam heat are provided.

Steam and Hot Water Supply to Head-house.

A supply of live steam is furnished for cooking and warming purposes in the head-house, restaurant, kitchen, and serving rooms. An additional supply is provided for heating water in certain closed water-storage heaters for furnishing hot water to outlets in the lavatories, kitchen, bath rooms, porters' rooms, and other points throughout the head-house. Steam is taken from the general main supplying head-house and car-heating outlets, and a portion of the supply is reduced by a regulating valve to the point desired by the kitchen employees.

The hot-water storage heaters are made of wrought iron, with removable cast-iron heads. Heavy copper steam coils are placed in the heaters, and are supplied with live steam at boiler pressure, the condensation being dripped by traps. An adjustable automatic thermostat is attached at each heater to maintain a constant water temperature.

Three of these heaters are used, and are located in their respective centres of distribution. Well-covered hot-water mains are

FIG. 206.—INTERIOR OF TRAIN SHED AT ENDS OF STUB TRACKS, SHOWING STEAM AND AIR CONNECTIONS AT BUMPERS. ONE OF THE ELECTRIC BAGGAGE LIFT ENCLOSURES IS SHOWN IN FOREGROUND.

run from each tank to supply smaller pipes which run to the outlets. These are also looped back to the heaters by return-pipe mains, so that a gravity circulation of the hot water is maintained in all pipe lines as close as practicable to the outlets. Accompanying illustration (see Fig. 204) shows one of these hot-water storage heaters.

Fire Protection.

The expenditure which would be warranted to give a good degree of protection against loss by fire was very largely a matter of judgment; determined, also, to some extent, by the methods commonly used in Boston to effect similar results.

The general methods considered were:

(1) Hydrants in yards and outlets in buildings, with necessary hose runs supplied from city pressure, roof tanks, or fire pumps.

(2) Automatic sprinkler service, with or without sprinkler electric alarms.

(3) Automatic electric thermostat alarms, with annunciators in buildings and fire department.

(4) Watchman's service, with recording clocks.

(5) Private fire alarm companies, alone or in conjunction with other methods.

After much consideration, it was determined to install system (1) only at present, supplementing it with watchmen making frequent rounds. Adequate provision was made for the subsequent addition of any of the other systems so far as it should be deemed desirable so to do after experience in the actual use of the station, and after more complete knowledge of the provisions likely to be made by the city of Boston for the protection of the territory occupied. An exceedingly good high pressure city water supply system existing in the adjacent streets, with a pressure maintained at 90 pounds by direct pumping, rendered the installation of fire pumps on the terminal property unnecessary and seemed the surest and best means of obtaining the requisite supply and pressure.

As the water department regulations limit the size of a service from the high-pressure mains to a pipe 4 inches diameter, it was concluded to run a sufficient number of such pipes into the terminal property to supply the necessary number of hose outlets. Each 4-inch service pipe supplies a number of such outlets from a separate horizontal header run in the basements.

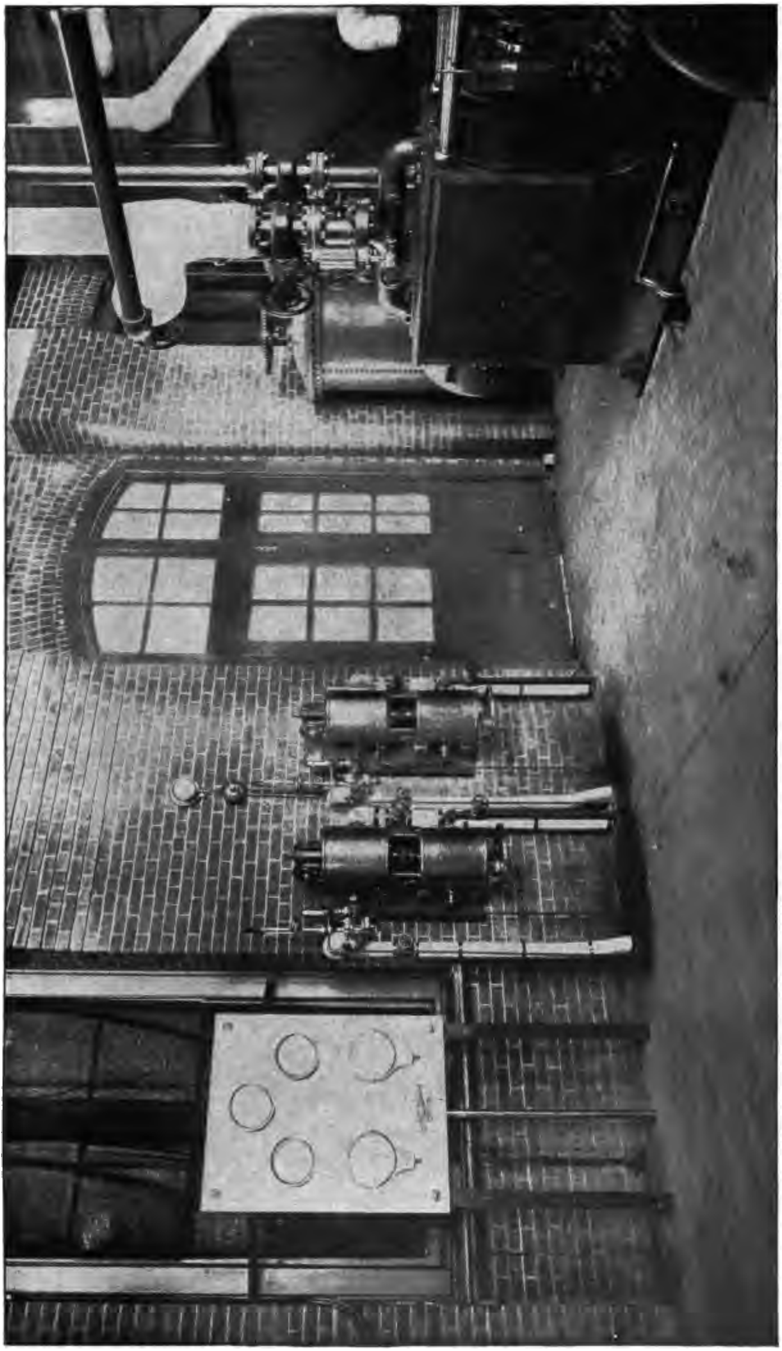


FIG. 207.—AIR-BRAKE PUMP OUTFIT FOR SUPPLYING COMPRESSED AIR FOR CHARGING TRAIN BRAKES WHEN LOCOMOTIVE IS DETACHED. LARGE AMMONIA COMPRESSOR CYLINDER OF ICE PLANT AT RIGHT, AMMONIA GAUGE BOARD AT LEFT OF VIEW.

From these basement headers 3-inch risers were run up through the buildings to the roof, with outlets in the hallways of each floor, in the attic, and on the roof. These risers were spaced about 100 feet apart, and a length of 2½-inch fire hose, folded on a rack, was permanently attached to a hose valve at each floor. The roof outlets were protected from rupture by freezing by the use of dripped shut-off valves located in the attics, but handled from above the roof. The means installed seem well adapted to meet all probable needs of the terminal for service of its own.

An unexpected test of the system was given shortly after its completion by the early morning fire which has already been mentioned. A forge left burning over night on the roof by some contractor's men became upset, and the live coals burned through the roof covering into the attic. The resulting flames were discovered by an attendant of the ventilating system, who promptly used the hose to extinguish the fire before reporting the trouble, which would, if not so stopped, have proved serious. This was done with good judgment and but little damage by water.

Since the completion of this work, one of the auxiliary provisions contemplated in the original plan has been installed by The Boston Terminal Company. This comprises several fire alarm boxes, connected with the city fire alarm system, which can be rung from 22 push buttons located in various places.

Elevators, Baggage and Express Lifts.

The determination of the type of elevators, and provision for power for their operation, involved conditions not met in other terminals. Elsewhere, the conditions have been suitable for the usual type of hydraulic passenger and freight elevators and the ordinary hydraulic plunger baggage lift. Moreover, at the time existing terminals were built, no other good method than the hydraulic was available, and inspection of terminal elevator practice therefore aided but little in the solution of the problem.

The ordinary form of baggage lift used at the railroad terminals is well represented by those in use at the Pennsylvania Railroad terminal at Jersey City, where a platform 22 feet by 9 feet, and weighing approximately two tons, is handled by a 12-inch plunger working under about 225 pounds per square inch. Platforms are stiffly guided at points 4 feet 6 inches above and below floor, thereby giving a spread of 9 feet to resist strain on plunger, but requiring protective railing above, and about 5 feet of pit

below floor levels, exclusive of provisions which have to be made for other parts of the apparatus.

Wherever baggage lifts have been used previously, three to five have been usually sufficient, and they have been located within small distances of each other. They have not been exposed to freezing weather, and if located near tide water the conditions have been such that failure of joints involved no more penalty than the inconvenience of flooding the elevator pit.

At the South Station, in Boston, conditions were far more complicated, and in some respects difficult of fulfilment with then standard apparatus. The elevator installation comprises the following:

3	five-story passenger elevators (in one battery)	speed	250	feet.
1	six-story " elevator (alone)	"	250	"
1	two-story " " "	"	250	"
1	one-story freight " "	"	100	"
1	" " " "	"	100	"
15	" baggage and express lifts	"	75	"
2	two-story " " " "	"	75	"

Of these 24 elevators, the first 7 might have been handled by any method, so far as surrounding conditions and restrictions were concerned; but the baggage lifts were subject to special limitations as follows:

1st. Prohibitions against piercing waterproofed construction, as would be necessary if the usual form of hydraulic plunger lift was used. This restriction applied more especially to 3 of the lifts.

2d. No projecting structure was allowable more than about 3 feet above the level of the train-shed floor.

3d. At least 8 of the 17 lifts were located in situations subject to freezing temperatures.

4th. These lifts were located at great distances from each other and from source of power, being scattered over an area covering many acres.

For the operation of the elevator installation four methods were considered:

1st. Hydraulic (pressures not exceeding 200 pounds).

2d. High-pressure hydraulic (with pressure 600 pounds or above).

3d. Hydro-pneumatic.

4th. Electric.

The first named involved plunger lifts, piercing waterproofing; required pumps, accumulators, and an oil or glycerine and

FIG. 208.—MAIN STAIRWAY HALL. THREE MAIN PASSENGER ELEVATORS IN BACKGROUND; FIRE HOSE AT RIGHT.

water distributing system with necessary returns, covering a large area. Plungers would be exposed to corrosion from tide water, and would require protection by outer casings. With the single plunger, substantial guiding structures projecting above train-shed floor would be required, and with two plungers undesirable automatic devices would be needed to equalize movement of plungers. This system was most expensive to install, and its first cost practically prohibited its use.

The second method had all the features of the low-pressure system, except that it was feasible to avoid piercing waterproofing by using horizontal plungers placed in pans sunk in concrete floor. It involved, however, very high-pressure pumps and pipe lines, a large steam accumulator in power house, a weighted accumulator requiring much height located in head-house; a smaller one in express building, and the usual auxiliary pump required in connection therewith. Its use required the introduction of a new class of service in the system, and although largely reduced from low-pressure system, the cost was still unduly high.

The third method, namely hydro-pneumatic, was regarded as merely a modification of the hydraulic, compressed air being substituted for the purpose of distributing power; the air displacing oil in pressure tanks to operate the elevators hydraulically with the same limitations and objections as for the low-pressure hydraulic service. This system was also very high in first cost, and its use was never seriously considered.

The fourth, or electric method, was practically free from all limiting conditions. It could be supplied with power from an existing system of distribution, which power could be economically generated and distributed. It simplified power house, reduced pipe systems with attendant leakage, and introduced no different class of inspection other than that already provided for the electric motors, electric lighting, etc. Under the conditions met at the terminal, it was the most efficient in operation, and required no relay other than was necessary to provide for other electric service. Under the circumstances, the advantages were largely in favor of an installation of electric elevators, both on account of the superior way in which they met the unusual conditions, and because also of the considerable saving in cost possible with their use. For the difference in first cost between electric and hydraulic systems at this terminal, all the electric operating and controlling devices could be entirely replaced about every six years during

the life of the terminal, and thereby make it pecuniarily possible to take advantage of improvements in such apparatus to such an extent as might be desirable.

The decision to use electric elevators and lifts was therefore made final, and a peculiarly simple and efficient design was made for the baggage lifts to meet the most limiting conditions encountered in several of the lifts operating between the platform level of the main train shed and the passenger platforms at lower suburban loop level. This was accomplished by doubling the gear of a standard freight pattern in a manner permitted by the 3-foot thickness of the iron train-shed floor at the points in question, and within which the controlling and operating mechanism could be placed. This design involved two desirable features; namely, accessibility from above, and avoiding running chains or ropes on a bight.

The platforms were suspended at corners by chains, connected with winding drums driven by longitudinal shafts at either side of the platform, the chain arrangement and design of lifts being shown on the accompanying illustration.

The design of apparatus for passenger and freight elevators was of the standard type made by the Sprague Elevator Co. Elevators are located as shown on general plan (Fig. 156) accompanying this paper. The passenger elevators were designed for carrying a live load of 2,500 pounds at full speed and 4,000 pounds at a reduced speed; freight elevators, 2,000 pounds, and the baggage and express lifts, 3,000 pounds each. The platforms of the baggage and express lifts were each made 6 feet wide and 15 feet long.

One of the most difficult problems to solve in a safe, simple, and rugged manner under the limitations imposed by traffic requirements was the provision for suitable protection around openings for baggage and express lifts. The following features were regarded as essential:

1st. That all gates or other protection must be so arranged that lifts could not be started until the gates were closed.

2d. That elevators and gates be operated from either above or below.

3d. That all elevators in train shed (excepting one) should have means for simultaneously closing and opening gates at both ends of the lift platform.

4th. That such gates should be automatically latched by

movement of elevator platform, and so interlocked that it would be impossible to open gates except with elevator platform at top or so near the top that no harm could come from such opening or to start lifts at any position unless gates were closed and locked.

5th. That suitable bar or other protection be provided in lower level in each case in such a manner that it would be automatically removed when lift platforms were at lower level.

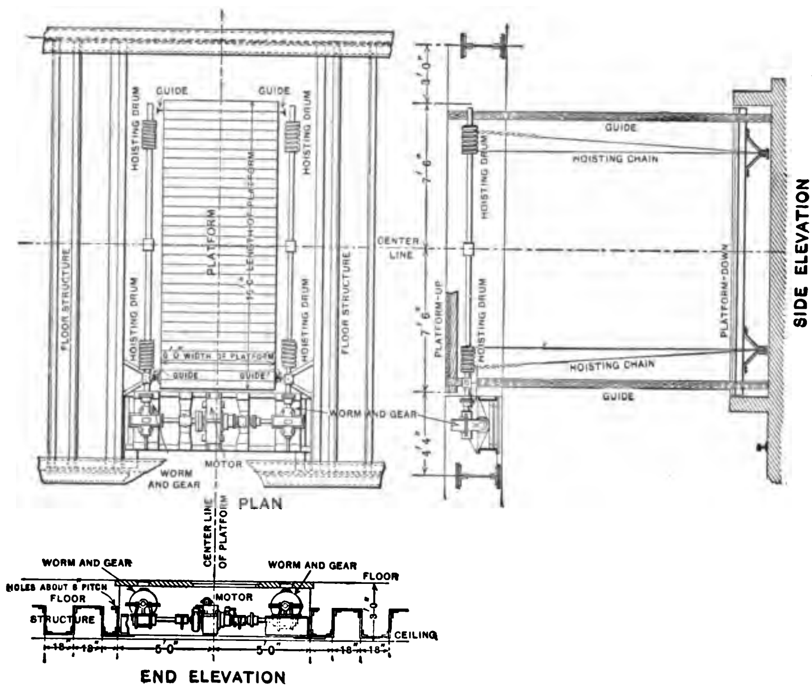


FIG. 209.—SPECIAL ELECTRIC BAGGAGE LIFT.

6th. That all lifts and gates in train shed could be operated from either end of the platform.

This problem was largely worked out by the resident engineer of The Boston Terminal Company, who designed a very rugged and substantial sheet-iron frame about $3\frac{1}{2}$ feet high at either side of each lift opening, and provided at either end of the opening and between frames an iron swinging gate, all being adapted to the various mechanical and electric interlocking devices. This framework cannot readily be wrecked by a heavy truck, and the

FIG. 210.—THREE MAIN PASSENGER ELEVATOR MACHINES AND CONTROLS, LOCATED IN BASEMENT UNDER MAIN STAIRCASE HALL.

gates swing entirely clear and out of the way when open. The gates are arranged so that they both open and close together, and are so interlocked by contact latches that lifts cannot be operated until gates are closed and locked. This arrangement is also such that the gates cannot be opened if the platform is more than a few inches below the upper platform level.

The lifts are operated by foot pushes, a set being located at either end of the platform. The lifts are all supplied with call bells and automatic gates at the lower levels. This type of apparatus is used for 15 of the 17 elevators; the other two, being for two-story service, were provided with ordinary form of drum freight machine, overhead sheaves, and safety devices.

To facilitate the handling of baggage and express matter, a system of subways, connecting with baggage room and express building basements, has been built, and several of the baggage lifts connect these with the train-shed level. These subways are shown on general plan (Fig. 156), and accompanying illustration shows the principal one in perspective. This arrangement not only facilitates the handling of baggage and express matter, but greatly reduces the baggage nuisance on train-shed platforms by diverting a large portion of the trucking to the subways.

Current for the operation of the elevator motors is derived from same bus bars, supplying current to all other electric service throughout the premises, through a loop feeder of uniform size carried through main and transverse subways and building basements.

Except to an unimportant degree, the elevators are located on or near the line of the loop circuit, and the conditions of operation are such that the loop feature in feeder system has made possible an important averaging in the amount of current required for elevator operation and substantial savings in feeder capacity necessary to provide. The entire elevator installation has been in operation for some time under severe conditions, and has been entirely satisfactory in every respect.

The baggage and express lifts were designed to carry a live load of 3,000 pounds at 75 feet per minute through an average rise of 16 feet, the lifts being operated intermittently, some much more so than others. When completed, it was thought advisable to test one of them, to destruction if necessary, to bring out any possible points of weakness. One was therefore loaded with its full 3,000 pounds live load, and an electric starting and stopping

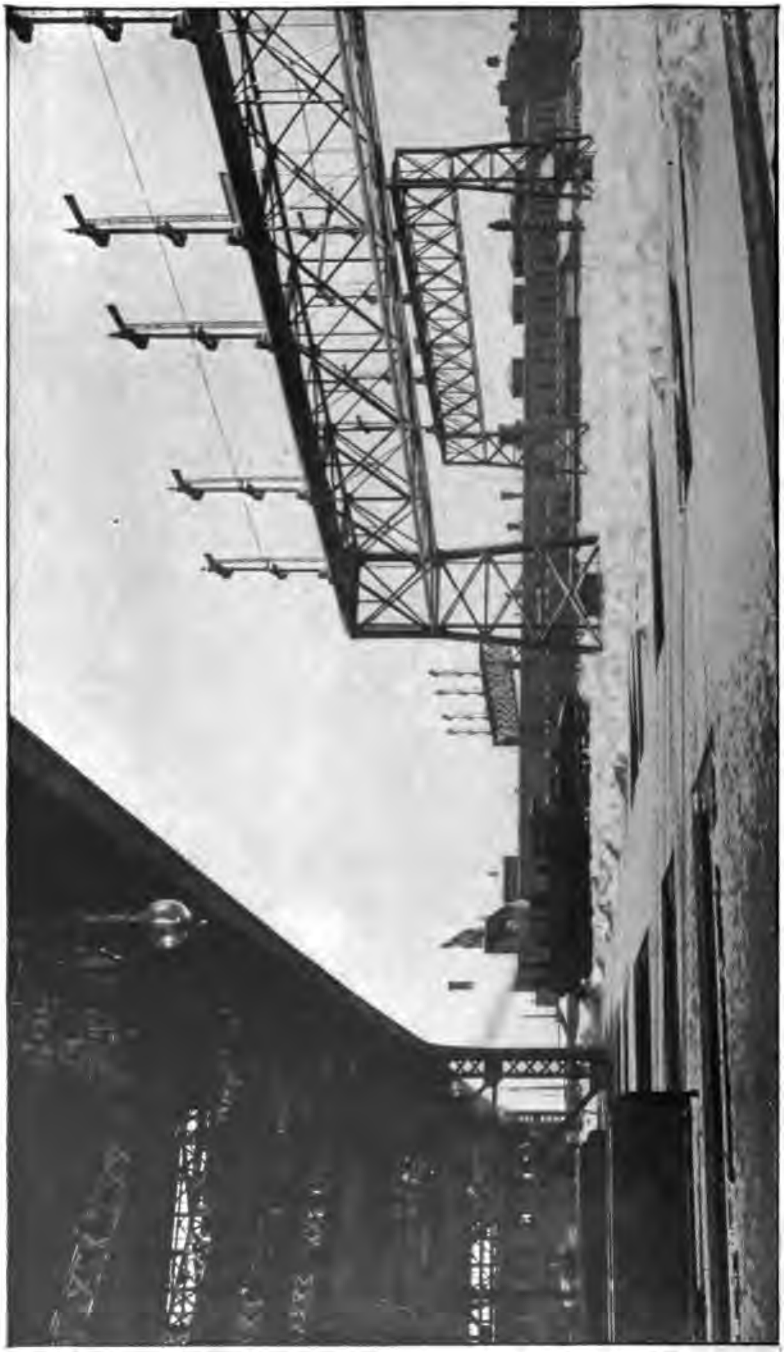


Fig. 211.—Southern End of Train Shed in Winter. Baggage Lift Enclosure at Left. There are Five of these Located at this End of Shed, Connecting with Baggage Subway, and all are Exposed to Rainstorm, Sleet, Snow, and Freezing Temperatures. (See also Fig. 156.)

FIG. 212.—ONE OF THE SEVENTEEN ELECTRIC BAGGAGE AND EXPRESS LIFTS, SHOWING IRON TROUGH FLOOR CONSTRUCTION, WITHIN THICKNESS OF WHICH OPERATING MECHANISM WAS PLACED AND WATERPROOF FLOOR BELOW. DISTRIBUTING CENTRE NO. 7, BEFORE INSTALLATION OF CABINET, IS SHOWN AT RIGHT OF VIEW.

FIG. 213.—BAGGAGE SUBWAY UNDER TRAIN-SHED TRACKS. THERE ARE FIVE ELECTRIC BAGGAGE LIFTS LOCATED AT THE FIVE RECESSES IN THE RIGHT-HAND WALL.

device was so set as to automatically trip at each end of the lift, and the platform allowed to thus run at full speed with full load for 10 hours. Careful inspection during and after the test showed the entire apparatus to be in perfectly normal condition, no weakness being developed.

DISCUSSION.

Mr. George I. Rockwood.—To deliver any eulogy of the Southern Terminal at Boston would be something like patting the Forth Bridge on the back. It is too big for any man to attempt to applaud it in the ordinary way. Every engineer who lives in the vicinity of Boston has, of course, seen the station, and on one occasion I was shown about this engineering plant by one of the sub-contractors. I did not wish especially, in rising to speak on this paper, to refer to the mechanical details of the plant, for I think that, perhaps, to us as a society the most important single feature in the paper is that which deals with the novel fact that the contract was let to a firm of engineering contractors who were also the engineers of the plant, although there were Mr. Leavitt and his board of engineers over all, and theoretically we have a consulting engineer and a firm of contractors, as is customary. But, as I understand it, practically the fact was that Westinghouse, Church, Kerr & Co. actually assumed the design of, as well as the contract for, all the details and improvements in the general arrangement. The question arises therefore whether the position occupied by this company is, in engineering work in general, one which is to be commended as a proper course to pursue, or an expedient policy to be followed in the future; and whether the engineer as such is going to join a corporation sooner or later and work in its interest, or whether an engineer as such is in the future to have complete responsible charge. I believe it is customary in New England for engineers to simply specify the goods that are to be bought, but not to buy the goods themselves. In my own case that is not so. I have had but one installation where I have not bought everything that was bought. I have been made an officer of the company; that is to say, I have been given a power of attorney from every corporation with which I have ever done considerable business, with this one exception, and that is possibly also a unique position to occupy, for it was not premeditated on the part of these people who employed me; it was my own desire. I have found that an engineer who occupies

that relation to a company—the relation of a purchasing agent—occupies a very advantageous position in behalf of the company. He also occupies a position of great temptation and great responsibility. Nevertheless it can be said that the contracting engineer, who also is the designing engineer, is tempted twice to pervert his powers where the purchasing agent is tempted once. The purchasing agent gets his commission from the corporation which he serves, and is supposed to take no commission from any other living soul who deals with him. He is therefore in a position to effect the best trade, because he knows the technical merits of the different articles offered, and he is also known to be the responsible buyer. But the contractor who also is the engineer has, of course, to make a percentage on the goods, and then, after receiving the contract and being his own inspector, may design the goods to enlarge the percentage. We come back to the morality of the contracting party after all, and I am not prepared to say that I believe it is unwise to employ a contracting firm of engineers as the designing engineers. I think it comes back to the question of man and man, just as all such questions finally do; but the very worst possible policy which can be followed, in my opinion, by any corporation is to suspect either its engineer, or, provided the contractor is also the designing engineer, its engineering contractor. Such beautiful relations must exist between the contractor and the party of the second part where such a contract is entered into, as described in this paper, as do not perhaps have to exist under other forms of contracting to get the same results. I have heard it said that the great ships of the White Star Line have nearly all of them been bought without any legal instrument passing between the buyers and the sellers. I do not know from my own knowledge whether that is true or not, but I was told that the corporation owning the ships decides to buy the ships, and that then its managing director goes to the firm of Harlan & Wolf and sees to getting the ships built; and they are built. Probably that is the highest relationship that can exist between the contractor and the buyer, but it is altogether too good to be true in ninety-nine out of a hundred cases. I incline for my own part towards the employment of engineers who are utterly disconnected from any firm, and placing absolute reliance upon their judgment, financial and technical.

Mr. William Kent.—The paragraph to which Mr. Rockwood refers I think is the most important in the paper, and I hope that

the whole subject, stated there in outline, will be made the subject of discussion. I would like Mr. Kerr, if possible, either in this discussion, or in a later paper hereafter, to answer this question, if he can put himself in the position of a purchaser, of the man who wants to buy a very large plant with every kind of apparatus, what is the best way for him to get the best thing and not pay an extravagant price for it? There are several different ways of getting plants built. The way I was accustomed to in Pittsburg, where I lived twenty years ago, was that a man who wanted an extensive plant would go to his friend in the neighborhood, who did the thinking for that locality, and say: "What do you think I had better have?" He would write a few letters to the people in town that built that sort of plant, and they would put up boilers and engines and machinery just as they used to do before. The result was that he got a pretty good job as regards strength and durability, but there was no progress. It was not until new blood came in with new ideas that anything was done better than that. I asked a mill owner one day if he was going to put in a Corliss engine or a Porter-Allen engine. He said: "We are going to put in an old-fashioned slide-valve engine. Nothing else for us." They kept on that way. That is one kind of engineering. The other way is the way followed by the Calumet and Hecla mine. They employ Dr. Leavitt to do their engineering, and I understand he designs every detail and has the things all built to order. That is an excellent method for such concerns as the Calumet and Hecla. Then there is another method—the consulting engineer's method, the English method, and that is a very good one. Then there is the day's labor method. I understand a contract is now being executed in this city where the man does it for cost plus 15 per cent. profit, and there are several men engaged in carrying brick from one pile to another and back again, and that is all charged in order that the contractor shall get this 15 per cent. on useless labor. Then there is this new way of Westinghouse, Church, Kerr & Co., which I think is quite unique. I do not quite understand it. I hope Mr. Kerr will give us more particulars of how this is done, why it is done, and why it is best that it should be done.

A friend of mine came to me the other day and said: "I want to get an electric plant, say 50 kilowatts or so; I want a boiler, engine, dynamo, and all that sort of thing; how had I better get it?" I was not particularly caring for the job, and I said: "The

easiest way to do that probably is to find out where you want these lights and how many of them, and go down to Westinghouse. Church, Kerr & Co., and they will do the rest." That was the easiest way out of that particular problem; but whether that is the best way or not I don't know. I will leave Mr. Kerr to tell us.

Dr. Robert H. Thurston.—I think the most important matter we have before us just now is the fact that we have this paper, and I want to congratulate the society very heartily in having secured this particular paper and a paper of this particular sort. I was talking with an old member of the Society yesterday, who said: "We have been getting too many professorial papers," and I agreed with him entirely. We came to this common conclusion: That because men of the other sort had not come forward, we had been reduced to dependence upon the professorial sort of paper.

While congratulating the Society on securing this admirable representative of a certain class of papers I want to congratulate also the gentlemen who prepared the paper, and particularly the firm that they represent, on the splendid way in which that work has been done. In the history of the profession there never has, I think, been a more magnificent opportunity more splendidly taken advantage of than is illustrated in the work of which this paper is a description. I think that fact is the really important thing. I think, further, that the fact that these gentlemen have come forward and given us so complete an account of their work and displayed the whole business end of it so frankly and completely, and have given such an admirable general description of methods of construction, of design, and of operation, will enable us hereafter to reduce the proportion of "professorial" papers, and to secure more generally the sort of paper that we need most. What the "professors" want, also, is this kind of a paper. What they present is the matter that they happen to know something about. What they wish to read is the thing they know less about, but which they are too often expected to know all about. If we can find in the *Transactions* of this Society, every year, a fair proportion of papers of this class, I think that not only the professors, but all other members, will be deeply grateful to the gentlemen who present them; it will be vastly to the advantage of the Society as a whole. I also feel grateful to the gentlemen presenting the paper, because they are setting so good an example to the younger members who are now coming forward and who, more than the

older members, have usually had opportunities of preparing themselves to tell what they have done, as well as of doing things in modern ways, and we now look to the junior members of this Society to study these papers with care and, later, to show us how our papers can be improved upon, even if they cannot show us how the work is to be improved.

A Member.—Referring to the saving of about $100,000 on three-quarters of a million on this contract, it is to be expected there would be saving from the method of designing. Apparently this work was contracted for at somewhere near the bottom of the market on metals. I would like to ask Mr. Kerr if any portion of the saving of $100,000 on three-quarters of a million might not be due to the price of material at the time the contracts were made.

Mr. Kerr.—It really had nothing to do with it. The $100,000 mentioned is an estimate made by comparing what other terminals paid for certain things and the cost of similar things here, equated as nearly as could be by allowing for the difference in size and amounts of apparatus installed. In addition to this there was a further saving due to prices of material. The difference was chiefly represented by what could have been saved in the other terminals if their work had been correlated instead of divided into separate jobs with no relation between them. I could tell you of a terminal where a power plant was installed with its boilers for 125 pounds; meanwhile the heating of the head-house was so planned that it could not be done on exhaust pressure, nor on boiler pressure, and they put in another set of boilers. That terminal to-day has a double set of boilers.

The Member.—I am glad to hear this reply, for this reason, that this saving of $100,000 is due to the use of engineering brains. I am glad to hear it.

Mr. John Platt.—The whole tendency seems to be to discuss the question of the saving made by the method employed in contracting for and carrying out the work on this building. We were just told that it is the question of the engineering brains that brings it about. Now the whole thing has been discussed a good deal at the present time in a series of articles in London *Engineering*, in connection with the question of American competition. The consulting engineer is referred to also, and his connection with the work; that it is a very important one is shown by the methods of carrying out work in England, particularly when comparing them with the methods in this country, and the

action taken generally by the consulting engineer, particularly in London, in relation to contractors. There the whole tendency seems to be, as much as possible, to make everything and design everything as different as a man can from the ordinary standards, and to cause the contractor as much trouble as possible. This is putting the worst part of it forward; but there is a great deal of it done. I know a great many offices in London where this method is carried out. Then here the consulting engineer places himself much more closely in touch with a manufacturing establishment, and designs the work so that they can carry it out economically. If people want a particular plant, and they simply go to the contractor and say, "We want so and so, and you design it and give us the price for building a good plant," no inspection being called for at all, and the contractor being allowed to make just what he sees fit, and when he can do this, of course, the cost is cut down to a minimum. I was very glad to hear one thing; viz., that Mr. Kent should ask for a paper which should put before the Society the whole subject as between the two methods —the extreme English method and the method adopted somewhat in this country—and to point out which is the better one for us to adopt.

Mr. Reginald P. Bolton.—Mr. Kent could himself write such a paper with considerable force, because he occupies the position of a consulting and independent engineer, and it is only from that standpoint that this question can be properly treated.

One point that was mentioned by Mr. Kerr in connection with his last remarks I think bears very greatly on the whole subject. He said that the architect did this and the architect did the other. Those are the people who make all the trouble. They stand between the consulting engineer and his living, and they get the contracting engineer to do the work for them. The architect who laid out that faulty system referred to was paid two and a half, possibly five, per cent. for doing the work he did so badly. If he was paid for doing the whole work, then Mr. Kerr's firm carried out the work for him in the first-rate manner described, and saved him that amount of money. That sort of thing is going on in this city every day in the year. The architects in this city are 550 in number, and out of that lot there are not more than twenty who employ engineers and pay them. Out of the rest another twenty have their own engineering draftsman in their office, whom they employ to lay out, as they say, engineer-

ing work—a class of man of limited experience. The other 510 uniformly get their whole engineering work done for them by contractors for nothing. That is a standing scandal, to my mind, and it has grown out of the gradual growth of much of the architectural work into engineering work, which has now gone beyond the stage where an architect can properly deal with it. That is known to all gentlemen who are engaged in manufacturing business, who have to go to great expense to prepare plans for this class of professional men, who send them sketches of a building and expect a steel structure to be designed, or send them a ragged sketch of a building and expect it to be heated for them, and the question has cropped up from time to time, but has never been seriously dealt with. The architectural societies must be well aware that this is the state of affairs, and it seems to me it is time that the engineering societies took the question up, and insisted that the engineering element in this country have its share of what is paid out for engineering work, because a double loss is occurring. Not only is the engineering profession not receiving what it ought to have, but it is actually having to do work for nothing, for which the architects are putting the money in their pockets. This work is not merely in relation to small buildings, dwellings, etc., but it has got up to the stage where architects undertake to tackle power stations, so that it becomes a very pertinent matter for the engineering societies to deal with.

With reference to the question of a contractor being allowed to draw specifications, there is another method which I see very much employed, especially in public work, and which is a very poor one, and that is, while employing engineers, to instruct those engineers to prepare specifications, which I call fishing specifications, which are simply sent out to cover any class of machinery which will by any hook or crook fit into the circumstances that are required. That practice is very disastrous to the purchaser and very often to the seller, for the reason that under such specifications as that a large number of plans have to be prepared at great cost to the general trade. Out of them probably the lowest bidder or the most favored bidder has his bid accepted. His apparatus is ordered to be installed, and is then installed under the specification, which contains provisions which do not specially relate to his machine, but to any class of machine. For instance, I have been for several years engaged for the city of Brooklyn in endeavoring to see carried out an in-

stallation of an important pumping plant of direct-acting tri-compound engines, under a specification which was manifestly written for a fly-wheel engine of a totally different character. The consequence is that in a large number of detail points, where the circumstances of the plant would require certain apparatus, no provision of the specifications can be made to apply. That sort of thing comes up constantly before consulting engineers.

Mr. Platt's reference to the difference between English practice and American practice is somewhat to the point. English engineers are very fond of designing special machinery. That prerogative is not entirely their own, however. It is done to some extent in this country. It is perfectly practical to draw a specification which will include certain standard machinery; but when it comes to the details of connection and the specialties which are required in those connections, then the engineer's ability and knowledge should come in, and he should define precisely what he wants and he should be able to design those things in detail so that they should not be laid as a burden on the contractor. For when all is said and done, somebody has got to pay for designing and for the brain work in connection with all this work, and if the contractor does it, acting also as consulting engineer, he has somewhere or other to make a profit. It has got to be paid for in the price of his contract. Otherwise he is at a loss, and his standing charges are running up against him.

I have been told that, in connection with steel structural work, some of the large firms maintain, not merely a dozen men, but scores of men—in one case over a hundred men—making designs for the steel structure of buildings, which designs are given away gratis, and for which they charge absolutely nothing. Now, they must in some way get money for doing that, and they add it on to the price of those contracts which they obtain. I think this state of affairs is not a right one, and calls for some action on the part of this Society, and for its influence to get the brain work of designing engineering appliances and engineering plants into the hands of the proper class of men.

*Mr. Kerr.**—I seem to have been called upon to say something in respect to several points. Mr. Kent has asked that a paper on the subject be written at some future time. I have not much use for anything written a year or two hence. It should be either written now or not at all. The subject is interesting. I think

* Author's closure, under the Rules.

many of the remarks made are timely and well taken. A good deal depends on the point of view.

I think the easiest solution of the questions raised is for us to settle them through such tribunal as we may appoint to determine just what kind of food we shall all eat and what kind of clothes we shall all wear, and what we shall all do for amusement. There are different ways of doing things, and different people believe that certain ways are better than others. The good ones eventually succeed and the bad fail. It is easier to discuss different ways than to decide which is the best. The broader the field of operation, the more room for many acceptable ways. If any one has something he thinks is good, the way to find out is to try it. If it succeeds it may be better than others have found, or possibly more meritorious than some one else understands. While more or less is said in the preface to this paper favoring the way in which this work was designed and executed, it is by no means intended to advocate it exclusively. It is simply a successful way which has met existing conditions and continues to meet them in many large enterprises.

In reply to Mr. Rockwood's remark regarding temptation, I think it is better to tempt one man twice than two men once. (Laughter and applause.) Mr. Rockwood has exemplified the fact that under the conditions and limitations of his practice he has found a preferred method. It is to his credit that he advocates the way which he has found good. Others evidently approve it, for they continue to use it, and that is why Mr. Rockwood continues to find it good. In the main, his way involves concentration of responsibility, which suits me. He is quite right in his statement to the effect that honesty must underlie any equitable relationship, and that honesty must reside in the individual man. This reminds me that there is another kind of honesty besides that which does not take money unlawfully. It is the honesty which neither deceives itself nor others, and which takes no risks for others on its own ignorance. It is just as requisite for success as common honesty.

I see no need of quarrelling with the ways of engineers nor of arraigning architects for their methods nor censuring contractors for contributing engineering design to the welfare of their work. It seems proper, however, to try to identify the results obtained, and determine how far they are due to method and how far they represent skill and knowledge independent of method. When

discussing engineering versus contracting, it may be also well to make clear whether we are considering contractors doing engineering or engineers doing contracting.

The tendency which has been referred to of manufacturing concerns making plans and specifications which some think should be made by consulting engineers has at least part of its origin in the fact that these concerns have found by experience that to get work done, done rightly and expeditiously, requires putting into the designs and specifications more constructive talent than is usually furnished by those who do not themselves construct, and the fact that the practice has grown rather than diminished is some indication that it is found good. It seems to have found peculiarly fertile soil in structural steel work. Certain causes have an old-fashioned way of producing certain results, and it may be accepted that there are some reasonable causes behind the willingness on the part of manufacturers to undertake at large expense to do work which, according to conventional customs, ought not to be required of them.

Something has been said of the engineering habit of "special design." I think all habits are likely to be bad. Even good habits may be inadvisable if they preclude the formation of any new ones equally good. The power to vary is an essential feature of life and progress, but efficient variation is a steady increase, progressive and reasonable, and is not to be confused with erraticness nor associated with inconsistency. Objections cannot truly be raised to designs and specifications because they are special, but because they are unreasonably special, and it is the unreasonableness which is objectionable. Who shall be the judge? There are many, but one of them should be the man who has to construct and guarantee the work.

I once heard an animated discussion which ended with the declaration by a contractor to a marine architect that "the yacht could rust on his stocks before he would rivet the centreboard trunk in a way which would send her to the bottom of the sea." His ultimatum won. He was only a boat-builder; but I knew that he was fitted by a foreign university education, by technical training, and constructive experience to be the only "judge" present.

But with reference to the main subject of engineering ethics, and whether the method adopted for creating this plant was in accordance with good custom, I would venture the assertion that

practice must always precede, and, if successful, the immaterial things, like customs, follow in the wake, adapting themselves to the force which pulls them along I believe that the process of evolution will go on and you cannot make laws that will stop it. I believe that there is room for every man with talent, and you cannot legislate any man into a place where he can exhibit talent which he has not got. The talents of some men are advisory. They can tell people how to do things, and though they could not do these things themselves their advice is good. Others seem to manage to get things done well. They lack initiative, but they know how to push what others have originated. Some are brilliant, but lack the fly-wheel of steady nerve. Some are not good advisers because they lack that gravity and balance which come only from making or losing money themselves and not for their customers.

There are restricted lines in which a man may become highly specialized. Such a man becomes a good adviser and competent to make designs and specifications of the things he knows all about. Others meanwhile develop similar qualities in other directions. Finally, many such men exist, but certain work is broader than any one of them. They need to work together to do a job right. One of them can take the whole job and do part of it well and the rest badly. That is the limitation of being only one man. If each of us could be a lot of men, each would be a lot better; but we are each one man. This encourages organizations of men to do the many things which one man cannot do but that many customers want done, and which need to be done together.

I might say a word about the difference between aggregations of men who advise and combinations of men who construct. I see no reason why wisdom should not flow from an aggregation of wise men. Sometimes it does. That is when they are more than wise. It is when they are all good, able, liberal, generous, practical, of strong personality, but not unduly tenacious, reasonably modest, and withal a hard combination to get. Such men may determine upon the best of many ways, but more often bodies of engineers thus associated in purely professional capacity finally determine upon a series of compromises, perhaps more or less mixed with antiquated methods and apparatus and a few of the most venturesome things upon which the boldest have insisted. I would rather have one good consulting engineer than

several. That one can, if necessary, get advice from others, which he can follow or not on his own judgment.

My experience with aggregations of constructors is different. The attributes enumerated above are desirable, but it is so much harder to compromise things in fact than on paper that there seems to be a peculiar realizing sense borrowed from the constructive faculty, which enables such men to help each other more than is customary in professional work. Even though this be true, the fact still remains that it is desirable and even necessary to have some one man over all, whose voice is final and upon whom the moral and financial responsibility rests heavily. After all it comes back to one man power, where some one must take the complete responsibility for making things right.

The present tendency in engineering seems to be to trust the judgment of the man who can himself do things. While a lot of engineers coöperate thus to actually execute work, some are not trying to perform the work themselves but are advising how it should be done, and honestly guarding their clients' interests, seeing that the work is executed as well as it can be done through contracts let in the ordinary manner; they do not pretend to do things. And I maintain that there is room for all in this great, big, progressive world. There are many, and the number seems increasing, who, when they want work done, care little and know less about details, but they want to know that it will accomplish a certain result and will cost a fixed price. Of those two things they must be absolutely sure. But who is to be responsible for producing that result and guaranteeing the cost? It must be the engineer-contractor. The necessities of others make room for him. No man, however able, no concern, however competent, will ever absorb all the work. Each will secure that which he can do best, and his talents will have full opportunity to earn all the money and all the reputation that they can bring.

Certain anomalies and difficulties exist of which we are all aware, but I will not enter into their details. They largely take care of themselves. Freak things don't win, but anything based on a fair exchange of money for the execution of good work and carrying of responsibility will always win. The work will distribute itself properly in quantity and degree to those who provide themselves with the various facilities for doing it. I think there will be no need for exact lines between one kind of

an engineer and another, no need of an engineering moral and penal code, and no room for those who do too much thinking and not enough acting. I think that the whole question really needs no answer. It resolves itself into room for all with different good ways of doing things. (Applause.)